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RESEARCH MEMORANDUM

THEORETICAL PERFORMANCE OF JP-4 FUEL WITH A 70-30 MIXTURE OF FLUORINE AND OXYGEN AS A ROCKET PROPELLANT

II - EQUILIBRIUM COMPOSITION

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

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SUMMARY

Theoretical rocket performance assuming equilibrium composition during expansion was calculated for JP-4 fuel with an oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight (fluorine-to-oxygen atom ratio of 2). Data were calculated for two chamber pressures and several pressure ratios and oxidant-fuel ratios.

The parameters included are specific impulse, combustion-chamber temperature, nozzle-exit temperature, molecular weight, molecular-weight derivative, characteristic velocity, coefficient of thrust, ratio of nozzle-exit area to throat area, specific heat at constant pressure, isentropic exponent, coefficient of viscosity, and coefficient of thermal conductivity. A correlation is given for the effect of chamber pressure on several of the parameters.

The maximum values of specific impulse for chamber pressures of 600 and 300 pounds per square inch absolute with an exit pressure of 1 atmosphere were 325.7 and 298.8 pound-seconds per pound, respectively.

A method for obtaining specific impulse for JP-4 fuel with OF_2 and O_3-F_2 mixtures is given.

INTRODUCTION

Mixtures of liquid fluorine and liquid oxygen with JP-4 fuel have been considered recently as possible high-energy rocket propellants (refs. 1 to 5). Better performance may be obtained from hydrocarbon fuels with certain fluorine-oxygen mixtures than with either 100 percent fluorine or oxygen. The reason for this is that fluorine burns preferentially with hydrogen, and oxygen with carbon. This is fortunate in

that the alternative formation of water instead of hydrogen fluoride would have led to lower combustion temperatures, and the formation of carbon tetrafluoride instead of carbon monoxide would have led to higher molecular weight. The result would then have been a lower ratio of temperature to molecular weight with a correspondingly lower performance.

According to data in reference 6, the optimum oxidant mixture with JP-4 fuel is about 70 percent fluorine and 30 percent oxygen by weight. Additional data were computed for JP-4 fuel with an oxidant containing 70.37 percent fluorine and 29.63 percent oxygen by weight (fluorine-to-oxygen atom ratio of 2) for both frozen and equilibrium compositions during expansion. These data, which cover a wide-range of oxidant-fuel ratios and pressure ratios, were calculated to aid in rocket design and for comparison with experimental results. 4046

The data for frozen composition during expansion are reported in reference 7. The subject report presents the data obtained for two chamber pressures on the basis of equilibrium composition during expansion. A correlation is given which permits the determination of specific impulse, characteristic velocity, ratio of nozzle-exit area to throat area, combustion-chamber temperature, and nozzle-exit temperature for a wide range of chamber pressures. An equation is given that permits estimation of specific impulse for a change in the heat of reaction of the propellant.

SYMBOLS

A	nozzle area, sq in.
a	local velocity of sound (velocity of flow at throat), ft/sec
C_F	coefficient of thrust, $C_F = g_c I/c^* = F/P_c A_t$
C_p^o	molar specific heat at constant pressure, cal/(mole)(^{o}K)
c_p	specific heat at constant pressure, $(\partial h/\partial T)_p$, cal/(g)(^{o}K)
c^*	characteristic velocity, $g_c P_c A_t/w$, ft/sec
F	thrust, lb
$f_1, f_2, \ldots$	functions
g_c	gravitational conversion factor, $32.174\left(\frac{\text{lb mass}}{\text{lb force}}\right)\left(\frac{\text{ft}}{\text{sec}^2}\right)$

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H_T^0 sum of sensible enthalpy and chemical energy, cal/mole

h sum of sensible enthalpy and chemical energy per unit mass,

$$\frac{\sum_i n_i (H_T^0)_i}{M(1 - n_k)}, \text{ cal/g}$$

I specific impulse, lb force-sec/lb mass

k coefficient of thermal conductivity, cal/(sec)(cm)($^{\circ}$K)

M molecular weight, $\frac{\sum_i n_i M_i}{1 - n_k}$, g/g-mole or lb/lb-mole

n mole fraction

n_c^* characteristic-velocity exponent, $\frac{\partial \ln c^*}{\partial \ln P_c}$

n_I specific-impulse exponent for fixed pressure ratio, $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{P_c/P}$

n_T temperature exponent for fixed pressure ratio, $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{P_c/P}$

n_ε area-ratio exponent for fixed pressure ratio, $\left(\frac{\partial \ln \varepsilon}{\partial \ln P_c}\right)_{P_c/P}$

o/f oxidant-to-fuel weight ratio

P pressure (sum of partial pressures), lb/sq in.

p partial pressure, lb/sq in.

R universal gas constant (consistent units)

r equivalence ratio, ratio of four times the number of carbon atoms plus the number of hydrogen atoms to two times the number of oxygen atoms plus the number of fluorine atoms in propellant, $\frac{4(C) + (H)}{2(O) + (F)}$

S_T^o entropy at pressure of 1 atmosphere, cal/(mole)($^{\circ}$K)

s entropy per unit mass, $\dfrac{\sum_i n_i (S_T^o)_i}{M(1 - n_k)} - \dfrac{R \sum_j p_j \ln(p_j/14.696)}{PM}$, cal/(g)($^{\circ}$K)

T temperature, $^{\circ}$K 4046

v specific volume

w mass-flow rate, lb/sec

γ isentropic exponent, $\left(\dfrac{\partial \ln P}{\partial \ln \rho}\right)_s$

ε ratio of nozzle area to throat area, A/A_t

μ coefficient of viscosity, poises = g/(cm)(sec)

ξ $\left(\dfrac{\partial \ln M}{\partial \ln T}\right)_s$, partial derivative of logarithm of molecular weight with respect to logarithm of temperature at constant entropy

ρ density, lb/cu in.

Subscripts:

c combustion chamber

e nozzle exit

i product of combustion including both gaseous and solid phases

j gaseous product of combustion

k solid product of combustion (graphite)

o conditions at 0° K

P constant pressure

P_c/P constant pressure ratio

s constant entropy

t nozzle throat

1 reference point

CALCULATION OF PERFORMANCE DATA

Performance data were obtained for two chamber pressures for a range of equivalence ratios and pressure ratios. These data were calculated assuming equilibrium composition during expansion.

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The computations were carried out by means of the method described in reference 8 with modifications to adapt it for use with an IBM card-programmed electronic calculator. The machine was operated with floating-decimal-point notation and eight significant figures. The successive approximation process used in the calculations was continued until seven-figure accuracy was reached in the desired values of the assigned parameters (mass balance and pressure or entropy).

Assumptions

The calculations were based on the following usual assumptions: perfect gas law, adiabatic combustion at constant pressure, isentropic expansion, no friction, homogeneous mixing, and one-dimensional flow. The products of combustion were assumed to be graphite and the following ideal gases: atomic carbon C, carbon monofluoride CF, carbon difluoride CF_2, carbon trifluoride CF_3, carbon tetrafluoride CF_4, difluoroacetylene C_2F_2, methane CH_4, carbon monoxide CO, carbon dioxide CO_2, atomic fluorine F, fluorine F_2, atomic hydrogen H, hydrogen H_2, hydrogen fluoride HF, water H_2O, atomic oxygen O, oxygen O_2, and the hydroxyl radical OH. The combustion products are assumed to be completely expanded within the exit nozzle; that is, exit pressure equals ambient pressure.

The graphite was assumed to be finely divided and in temperature and velocity equilibrium with the gases during the flow process.

Initial Data

Thermodynamic data. - The thermodynamic data for all combustion products except graphite, methane, the fluorocarbons, and water were taken from reference 8. Data for graphite were taken from reference 9, for carbon monofluoride from reference 10, for the remainder of the fluorocarbons from reference 11, and for water from reference 12. Data for methane were determined by the rigid-rotator - harmonic-oscillator

approximation using spectroscopic data from reference 13. The base used in this report for assigning absolute values to enthalpy is the same as that in reference 8.

The dissociation energy of fluorine was taken to be 35.6 kilocalories per mole, and the heat of sublimation of graphite at 298.16° K was taken to be 171.698 kilocalories per mole (ref. 14). The heat of solution of oxygen and fluorine was taken to be zero.

Physical and thermochemical data. - The properties of the fuel used in these calculations are typical of the JP-4 fuel delivered to the Lewis laboratory over a period of 2 years. The JP-4 fuel was assumed to have a hydrogen-to-carbon weight ratio of 0.163 (atom ratio of 1.942), a lower heat of combustion value of 18,640 Btu per pound, and a specific gravity of 0.769. Additional properties of jet fuels may be found in reference 15. 4046

The oxidant used in these calculations is a mixture of liquid fluorine and liquid oxygen. The heat of solution of this mixture was neglected. Several properties of the oxidants taken from references 8, 14, 16, and 17 are listed in table I.

Viscosity data. - The viscosity data for the individual combustion products were either taken from the literature when available, or estimated. The viscosities of F, H, H_2, and HF are given in reference 18. The viscosities of the remaining substances except H_2O were calculated using similar techniques. The viscosity of H_2O was obtained from a modified Sutherland equation (ref. 19).

Computation of Combustion Conditions

A combustion pressure was assigned (300 or 600 lb/sq in. abs). At this assigned pressure, the equilibrium composition n_i, enthalpy h (including both chemical and sensible energy), and entropy s were determined for three temperatures at 100° K intervals. The temperatures were chosen to band the value of enthalpy for the propellant mixture h_c. The formulas used to calculate h and s are

$$h = \frac{\sum_i n_i (H_T^0)_i}{M(1 - n_k)} \tag{1}$$

$$s = \frac{\sum_i n_i (S_T^0)_i}{M(1 - n_k)} - \frac{1.98718 \sum_j p_j \ln(p_j/14.696)}{PM} \tag{2}$$

Combustion composition corresponding to h_c was obtained by ordinary three-point interpolation of composition as a function of h. Entropy s_c corresponding to h_c was obtained by means of a three-point - three-slope interpolation of s as a function of h. The slope was obtained by means of the thermodynamic relation

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$$\left(\frac{\partial s}{\partial h}\right)_P = \frac{1}{T} \tag{3}$$

It is convenient to treat the products of combustion (sometimes a mixture of solid graphite and ideal gases) as a single homogeneous fluid. Therefore, the molecular weight of the combustion products M is defined as the weight of a sample (including gases and solid graphite) divided by the number of moles of gas, as given by the formula

$$M = \frac{\sum_i n_i M_i}{1 - n_k} \tag{4}$$

This value of M is suitable for use in the gas law

$$P = \frac{\rho R T}{M} \tag{5}$$

provided the solid phase is included in the density. Such a fluid will exhibit ideal properties as long as the volume of the gases is large with respect to the volume of the solid phase. The procedure is also consistent with the assumption that the solid particles are small enough to be considered gas molecules of extremely large molecular weight.

Computation of Exit Conditions

Calculation of parameters at assigned temperatures. - Exit temperatures were selected at 200°, 300°, or 400° K intervals to cover the range of pressure ratios from 1 to 1500. At these selected temperatures, the following data were computed assuming isentropic expansion and equilibrium composition: pressure, enthalpy, molecular weight, molecular-weight derivative, isentropic exponent, specific heat at constant pressure, viscosity, thermal conductivity, nozzle-area ratio, coefficient of thrust, and specific impulse.

Interpolation of throat pressure. - A cubic equation in terms of ln P was derived from the following function and its first derivative using the data at two assigned temperatures:

$$\text{function, } f_1 = \ln f_2 = \ln\left(\frac{h}{R} + \frac{\gamma T}{2M} - \frac{h_o}{R}\right)$$

$$\text{first derivative, } \frac{df_1}{d \ln P} = \frac{T}{2Mf_2}\left(\gamma + 1 + \frac{d\gamma}{d \ln P}\right)$$

(Values for $d\gamma/d \ln P$ were found by a numerical method.)

The two temperatures were selected to band the throat temperature. 4046 The pressure at the throat was found by interpolating $\ln P$ as a function of f_1 for the point $f_1 = \ln (h_c/R - h_o/R)$. At this point the velocity of flow equals the velocity of sound.

Interpolation of enthalpy. - Enthalpies were interpolated for a series of pressures including the throat pressure by means of quartic equations in terms of $\ln P$. Each of the quartic equations used was derived from data at two successive assigned temperatures and used to interpolate those points within the temperature interval. The data used in forming each quartic were the following function at one of the assigned temperatures and its first and second derivatives at both assigned temperatures:

$$\text{function, } f_3 = \frac{h}{R}$$

$$\text{first derivative, } \frac{df_3}{d \ln P} = \frac{T}{M}$$

$$\text{second derivative, } \frac{d^2f_3}{(d \ln P)^2} = \frac{T}{M}\left(\frac{\gamma - 1}{\gamma}\right)$$

Interpolation of temperature. - Temperatures were interpolated for a series of pressures including the throat pressure by means of cubic equations in terms of $\ln P$. Each of the cubic equations used was derived from data at two successive assigned temperatures and used to interpolate those points within the temperature interval. The data used in forming each cubic were the following function and its derivative at both assigned temperatures:

$$\text{function, } f_4 = \ln T$$

$$\text{first derivative, } f_5 = \frac{df_4}{d \ln P} = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{1}{1 - \xi}\right)$$

Interpolation of molecular weight. - Molecular weights were interpolated similarly to temperatures using the following function and derivative:

$$\text{function, } f_6 = \ln M$$

$$\text{first derivative, } \frac{df_6}{d \ln P} = \xi f_5 = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{\xi}{1 - \xi}\right)$$

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Interpolation of specific heat, isentropic exponent, and molecular-weight derivative. - Specific heats were interpolated for a series of pressures including the throat pressure by means of cubic equations in terms of ln P. Each of the cubic equations used was derived from values of specific heat for four successive temperatures and used to interpolate those points within the interval of the two middle temperatures. Isentropic exponents and molecular-weight derivatives were interpolated in a manner similar to that for specific heats.

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Accuracy of interpolation. - The errors due to interpolation were checked for several cases. The values presented for enthalpy, entropy, and specific impulse appear to be correctly computed to all figures tabulated. The temperature and molecular weight may in some cases be in error by a few figures in the last place tabulated. The derivatives may, in regions where they are changing rapidly, be in error by a few percent. However, because of uncertainties in thermodynamic data used, all values are probably tabulated to more places than are entirely significant.

Formulas

The formulas used in computing the various performance parameters are as follows:

Specific impulse, lb force-sec/lb mass

$$I = 294.98\sqrt{\frac{h_c - h_e}{1000}} \tag{6}$$

Throat area per unit mass-flow rate, (sq in.)(sec)/lb

$$\frac{A_t}{w} = \frac{2781.6\ T_t}{P_t M_t a} \tag{7}$$

Characteristic velocity, ft/sec

$$c^* = g_c P_c\left(\frac{A_t}{w}\right) = 32.174\ P_c\left(\frac{A_t}{w}\right) \tag{8}$$

Coefficient of thrust

$$C_F = \frac{g_c I}{c^*} = \frac{32.174\ I}{c^*} \tag{9}$$

Nozzle area per unit mass-flow rate, (sq in.)(sec)/lb

$$\frac{A}{w} = \frac{86.455\ T}{PMI} \tag{10}$$

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Ratio of nozzle area to throat area

$$\varepsilon = \frac{A/w}{A_t/w} \tag{11}$$

Specific heat at constant pressure, cal/(g)($^{\circ}$K)

$$c_p = \left(\frac{\partial h}{\partial T}\right)_P = \frac{C_p^o}{M(1 - n_k)} \tag{12}$$

where C_p^o is given by equation (37) of reference 8.

Isentropic exponent

$$\gamma = \left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s = \frac{a^2 M}{RT} \tag{13}$$

where a^2 is given by equation (32) of reference 8.

Coefficient of viscosity, poises

$$\mu = \frac{PM}{\sum_j \frac{p_j}{\mu_j/M_j}} \tag{14}$$

Molecular-weight derivative

$$\xi = \left(\frac{\partial \ln M}{\partial \ln T}\right)_s = D_A - \frac{\sum_i p_i D_i}{P} \tag{15}$$

where D_A and D_i have the definitions of reference 8.

Coefficient of thermal conductivity, cal/(sec)(cm)($^{\circ}$K)

$$k = \mu\left(c_p + \frac{5}{4}\frac{R}{M}\right) \tag{16}$$

The values of viscosity and thermal conductivity for mixtures of combustion gases calculated by means of equations (14) and (16) are only approximate. When more reliable transport properties for the various products of combustion become available, a more rigorous procedure for computing the properties of mixtures may also be justified. When solid graphite was present among the combustion products, it was omitted from equation (14).

THEORETICAL PERFORMANCE DATA

Tables

The calculated values of the performance parameters and equilibrium composition of the combustion products are given in tables II to VII. The properties of gases in the combustion chamber and the characteristic velocity are given in table II for each chamber pressure and equivalence ratio. Table III presents the values of performance parameters at assigned temperatures and constant entropy. These values were computed directly and used to interpolate properties for assigned pressure ratios. The values of viscosity and thermal conductivity of the mixture are also given in this table as functions of temperature. The performance parameters for small pressure ratios from 1 to 8 are given in table IV. These properties permit computations within the rocket nozzle and for finite combustion-chamber diameters. An example for this latter application is given in reference 20. Properties at the throat may be found where $\varepsilon = 1.000$. The values adjacent to the throat correspond to pressures 1.2 and 0.8 times the throat pressure.

The performance parameters for pressure ratios from 10 to 1500 are given in table V. This table gives sufficient data to permit interpolation of complete data for any pressure ratio within the range tabulated.

The performance parameters are summarized in table VI for expansion from chamber pressure to 1 atmosphere. The maximum values calculated for specific impulse for chamber pressures of 600 and 300 pounds per square inch absolute are 325.7 and 298.8, respectively, at 20.71 percent fuel by weight. This mixture corresponds closely to the chemically correct mixture for the formation of carbon monoxide and hydrogen fluoride.

Table VII presents the composition of the combustion products at the combustion temperature and various assigned temperatures at constant entropy.

Curves

The performance parameters are plotted in figures 1 to 6 for chamber pressures of 600 and 300 pounds per square inch absolute.

Curves of specific impulse are presented in figure 1 for pressure ratios from 10 to 1500 as functions of weight percent fuel. The maximum value of specific impulse occurs at about 21 weight percent fuel for all pressure ratios. The exponent n_I is also shown. 4046

Curves of combustion-chamber and nozzle-exit temperature for pressure ratios from 10 to 1500 are plotted in figure 2 as functions of weight percent fuel. The exponent n_T is also shown.

Curves of the ratio of nozzle area to throat area are plotted in figure 3 for pressure ratios from 10 to 1500 as functions of weight percent fuel. The exponent n_ε is also shown.

Figures 4 and 5 give the curves for coefficient of thrust and molecular weight, respectively, for pressure ratios from 10 to 1500 as functions of weight percent fuel.

Figure 6 presents curves of characteristic velocity as functions of weight percent fuel. Also shown is the exponent n_{c^*}.

The theoretical calculations of equilibrium composition in the combustion chamber showed that solid graphite was not present for the equivalence ratios of 1 to 1.6 (weight percent fuel, 14.83 to 21.79) and was present for equivalence ratios of 1.75 to 4.00 (weight percent fuel, 23.35 to 41.05). The appearance of solid graphite and carbon-fluorine compounds affected the values of the thermodynamic parameters and resulted in a break in the performance data in the region of 23 weight percent fuel. This break in the performance data is apparent in figures 1 to 6.

Effect of Assuming Frozen or Equilibrium Composition

The assumption of whether the composition remains constant during the expansion process (frozen) or is in continuous equilibrium affects the value of the performance parameters. A comparison is given in figure 7 between the values of specific impulse assuming equilibrium composition (this report) and frozen composition (ref. 7). The maximum value of specific impulse for a chamber pressure of 600 pounds per square inch absolute (40.83 atm) and an exit pressure of 1 atmosphere is 325.7 for equilibrium composition and 301.1 for frozen composition, a difference of 8.2 percent. The maximum specific impulse occurs at about 21 percent fuel by weight for both equilibrium and frozen compositions.

An example of the large effect of change of composition on specific heat and isentropic exponent is given in figures 8(a) and (b). For the stoichiometric equivalence ratio, the value for specific heat assuming equilibrium composition is, at about 2000° K, over 10 times the value assuming frozen composition. This large difference is due primarily to the rate of change of composition with temperature and only relatively little to the difference in composition. The value for isentropic exponent at about 1600° K is 25 percent greater for frozen composition than for equilibrium composition.

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Chamber-Pressure Effect

By use of suitable derivatives, performance parameters can be estimated with good accuracy at chamber pressures other than those given in this report. Derivatives which permit the calculation of I, T, ε, and c^* at various chamber pressures for fixed pressure ratios and equivalence ratios were obtained from the following equations:

$$n_I = \left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{P_c/P} = 86.4554 \frac{T}{I^2}\left(\frac{1}{M_c} - \frac{1}{M}\right) \tag{17}$$

$$n_T = \left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{P_c/P} = \left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{1}{1 - \xi}\right) - \frac{R}{M_c c_p} \tag{18}$$

$$n_\varepsilon = \left(\frac{\partial \ln \varepsilon}{\partial \ln P_c}\right)_{P_c/P} = (n_{A/w})_e - (n_{A/w})_t \tag{19}$$

where $$n_{A/w} = \left(\frac{\partial \ln A/w}{\partial \ln P_c}\right)_{P_c/P} = -\left(\frac{M}{M_c}\right)\left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{1}{1 - \xi}\right) - \frac{1}{\gamma} - n_I$$

$$n_c^* = \frac{\partial \ln c^*}{\partial \ln P_c} = 1 + (n_{A/w})_t \tag{20}$$

These equations, which were derived analytically from thermodynamic relations, are valid only for chemical equilibrium during expansion. The equations may be written in the approximate form:

$$I = I_1\left(\frac{P_c}{P_{c,1}}\right)^{n_{I,1}} \tag{21}$$

$$T = T_1\left(\frac{P_c}{P_{c,1}}\right)^{n_{T,1}} \tag{22}$$

$$\varepsilon = \varepsilon_1\left(\frac{P_c}{P_{c,1}}\right)^{n_{\varepsilon,1}} \tag{23}$$

$$c^* = c_1^*\left(\frac{P_c}{P_{c,1}}\right)^{n_{c^*,1}} \tag{24}$$

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where $P_{c,1}$ may be selected to be either 300 or 600 pounds per square inch absolute, provided that I_1, T_1, ε_1, c_1^*, and their derivatives are the corresponding values for the chamber pressure selected.

The derivatives obtained by means of equations (17) to (20) are shown in tables II to V and are plotted in figures 1, 2, 3, and 6.

To illustrate the use of these derivatives, suppose it is desired to obtain the value of specific impulse for a chamber pressure of 450 pounds per square inch absolute and a pressure ratio of 30.62 (exit pressure, 1 atm) for an equivalence ratio r of 1.5 (20.71 weight percent fuel). From figure 1(a) or table V, the value of I at this pressure ratio and equivalence ratio (but for a chamber pressure of 600 lb/sq in. abs) is 316.0 and the value of n_I is 0.0090. From equation (21),

$$\begin{aligned} I &= 316.0\left(\frac{450}{600}\right)^{0.0090} \\ &= 316.0\ (0.99741) \\ &\doteq 315.2 \end{aligned}$$

A comparison of the parameters obtained by means of the chamber-pressure correlation and by a direct calculation for two examples is given in the following table (r = 1.5 (20.71 weight percent fuel)):

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Parameter	P_c = 450 lb/sq in. abs P_e = 1 atm			P_c = 1200 lb/sq in. abs P_e = 1 atm		
	Estimated by correlation	Direct calculation	Error	Estimated by correlation	Direct calculation	Error
I	315.18	315.19	0.01	347.56	347.50	0.06
T_c	4424.2	4424.0	.2	4615.2	4613.4	1.8
T_e	2905.7	2905.6	.1	2403.1	2403.0	.1
ε	5.119	5.112	.007	10.009	10.002	.007
c^*	6789.3	6788.9	.4	6873.7	6872.0	1.7

It is expected that values estimated for other equivalence ratios and pressure ratios for any chamber pressure from about 150 to 1200 pounds per square inch absolute will have small errors in the order of magnitude shown in the previous table. A possible exception might occur when the value of the exponent is changing rapidly such as in the region where solid graphite first appears.

Estimated Performance of JP-4 Fuel with Ozone-Fluorine Mixtures or with Oxygen Bifluoride

The performance of other propellants having the same atom ratios as the propellant in this report, but with a difference in the heat content of the propellants or combustion products, may be estimated from the following equation (ref. 21):

$$I^2 = I_1^2 + B\,\Delta h_c + C\,(\Delta h_c)^2 \tag{25}$$

where Δh_c is the change in the heat content,

$$B = 87.0132\left(1 - \frac{T_e}{T_c}\right)_1$$

$$C = \frac{87.0132}{2}\left(\frac{T_e}{T_c^2}\right)_1\left[\frac{1}{(c_p)_c} - \frac{1}{(c_p)_e}\right]_1$$

and the subscript 1 indicates the values of the parameters before the change is made. Inasmuch as the data in this report are for an oxidant with a fluorine-to-oxygen atom ratio of 2, then equation (25) is applicable to a fluorine-ozone mixture having this same atom ratio or to oxygen bifluoride.

For example, assume that the performance is desired for JP-4 fuel with liquid oxygen bifluoride at an equivalence ratio of 1.5, a combustion pressure of 600 pounds per square inch absolute, and a pressure ratio of 40. The reaction may be written

$$CH_{1.942} + 0.9903\ OF_2$$

From reference 8, the difference in heat content between OF_2 and $\frac{1}{2}\,O_2 + F_2$ is 5844.3 calories per mole of oxygen bifluoride. Therefore, Δh_c is 85.15 calories per gram of propellant (fuel plus oxidant). 4046

From tables II and V(a) or figures 1(a) and 2(a) the values of the parameters are

$$I_1 = 325.0$$

$$T_{c,1} = 4479$$

$$T_{e,1} = 2769$$

$$(c_p)_{c,1} = 1.357$$

$$(c_p)_{e,1} = 0.489$$

These values yield the following:

$$I_1^2 = 105{,}625$$

$$B = 33.22$$

$$C = -0.00786$$

By equation (25),

$$I^2 = 105{,}625 + 33.22(85.15) + (-0.00786)(7251)$$

$$= 105{,}625 + 2829 - 57 = 108{,}397$$

$$I = 329.24$$

This compares with a value of 329.34 obtained by a direct calculation.

Equation (25) was used to obtain specific impulse at several equivalence ratios for JP-4 fuel with oxygen bifluoride and JP-4 fuel with an

oxidant containing 70.37 percent fluorine and 29.63 percent ozone by weight. The results are compared in figure 9 with the specific impulse data of table VI.

Use of Derivatives

The derivatives of the fundamental thermodynamic quantities have many useful applications. Equations (21) to (25) are examples of these applications.

All the relations between the first derivatives may be expressed in terms of three arbitrary first derivatives in addition to the fundamental quantities (ref. 22). Reference 22 presents a convenient scheme for expressing all first derivatives in terms of $(\partial v/\partial T)_P$, $(\partial v/\partial P)_T$, and $(\partial h/\partial T)_P = c_p$. In order to make use of the tables in reference 22, $(\partial v/\partial T)_P$ and $(\partial v/\partial P)_T$ can be obtained from the data in this report by means of the following equations:

$$\left(\frac{\partial v}{\partial T}\right)_P = \left(\frac{c_p}{P}\right)\left(\frac{\gamma - 1}{\gamma}\right)\left(\frac{1}{1 - \xi}\right) \tag{27}$$

$$\left(\frac{\partial v}{\partial P}\right)_T = -\frac{T}{c_p}\left(\frac{\partial v}{\partial T}\right)_P^2 - \frac{v}{\gamma P} \tag{28}$$

The dimensions of specific volume v in equations (27) and (28) which result from using the dimensions assigned to the other variables in this report are (cal)(sq in.)/(g)(lb force). For certain applications involving these derivatives, the dimensions of v are unimportant inasmuch as they will cancel. However, a conversion factor may be used when it is desired to obtain any other dimension for v. For example, 1(cal)(sq in.)/(g)(lb force) equals 606.84 cu cm/g.

SUMMARY OF RESULTS

A theoretical investigation of the performance of JP-4 fuel with an oxidant containing 70.37 percent fluorine and 29.63 percent oxygen by weight was made for the following conditions: (1) equivalence ratios from 1 to 4, (2) chamber pressures of 300 and 600 pounds per square inch, (3) pressure ratios from 1 to 1500, and (4) equilibrium composition during expansion.

The results of the investigation are as follows:

1. The maximum values of specific impulse for chamber pressures of 600 and 300 pounds per square inch absolute (40.83 and 20.41 atm) and an exit pressure of 1 atmosphere were 325.7 and 298.8, respectively.

2. Data are presented that permit interpolation of complete performance data for equivalence ratios from 1 to 4, chamber pressures from 150 to 1200 pounds per square inch absolute, and pressure ratios up to 1500. 4046

3. A method for obtaining specific impulse for JP-4 fuel with OF_2 and O_3-F_2 mixtures is given.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 6, 1956

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TABLE I. - PROPERTIES OF LIQUID OXIDANTS

Properties	Oxygen, O_2	Fluorine, F_2
Molecular weight, M	32.00	38.00
Density, g/cc	[a]1.1415	[b]1.54
Freezing point, $^{\circ}C$	[c]-218.76	[c]-217.96
Boiling point, $^{\circ}C$	[c]-182.97	[c]-187.92
Enthalpy required to convert liquid at boiling point to gas to 25° C, kcal/mole	[d]3.080	[d]3.030
Enthalpy of vaporization, kcal/mole	[c,e]1.630	[c,f]1.51
Enthalpy of fusion, kcal/mole	[c,g]0.106	[c,h]0.372

[a]At -182.0° C; ref. 16.

[b]At -196° C; ref. 17.

[c]Ref. 14.

[d]Ref. 8.

[e]At -182.97° C.

[f]At -187.92° C.

[g]At -218.76° C.

[h]At -217.96° C.

TABLE II. - THERMODYNAMIC PROPERTIES OF GASES IN COMBUSTION CHAMBER FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

Equivalence ratio, r, $\frac{4(C)+(H)}{2(O)+(F)}$	Percent fuel by weight	Oxidant-to-fuel weight ratio, o/f	Temperature, T, °K	Temperature exponent, n_T	Molecular weight, M	Enthalpy, h, cal/g (a)	Entropy, s, $\frac{cal}{gm\ ^{o}K}$	Specific heat, c_p, $\frac{cal}{(g)(^{o}K)}$ (b)	Isentropic exponent, γ (b)	Characteristic-velocity exponent, n_{c*} (b)	Characteristic velocity, c*, ft/sec (b)
Combustion-chamber pressure, 600 lb/sq in. abs											
1.00	14.83	5.743	4007	0.0351	22.24	2592.0	2.5230	0.869	1.196	0.0106	6203
1.40	19.60	4.102	4464	.0428	21.20	3064.9	2.6853	1.306	1.171	.0125	6757
1.50	20.71	3.829	4479	.0431	20.95	3175.0	2.7138	1.357	1.169	.0126	6814
1.60	21.79	3.589	4396	.0426	20.97	3282.1	2.7302	1.351	1.167	.0126	6749
2.50	30.33	2.297	3898	.0308	20.41	4128.8	2.8100	1.017	1.172	.0076	6420
Combustion-chamber pressure, 300 lb/sq in. abs											
1.00	14.83	5.743	3910	0.0358	22.10	2592.0	2.5851	0.924	1.190	0.0109	6157
1.25	17.87	4.595	4238	.0411	21.45	2893.9	2.6958	1.251	1.171	.0121	6543
1.40	19.60	4.102	4332	.0437	21.03	3064.9	2.7505	1.449	1.164	.0131	6697
1.50	20.71	3.829	4346	.0439	20.78	3175.0	2.7798	1.507	1.162	.0133	6753
1.60	21.79	3.589	4267	.0442	20.80	3282.1	2.7962	1.479	1.164	.0129	6691
1.75	23.35	3.282	4163	.0391	20.75	3437.3	2.8146	1.641	1.141	.0111	6667
2.00	25.83	2.872	4067	.0362	20.55	3682.7	2.8399	1.494	1.143	.0103	6594
2.50	30.53	2.297	3813	.0332	20.26	4128.8	2.8777	1.114	1.167	.0086	6384
3.00	34.31	1.914	3552	.0277	20.04	4523.9	2.9025	.959	1.176	.0066	6181
4.00	41.05	1.436	3095	.0153	19.59	5192.5	2.9267	.785	1.184	.0027	5819

[a]The base used for enthalpy is given in ref. 8.

[b]Parameter includes energy due to change in composition.

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TABLE III. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Equilibrium composition during isentropic expansion or compression from combustion conditions.]

(a) Combustion-chamber pressure, 600 pounds per square inch absolute

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(^oK)}$	Coefficient of viscosity, μ, micropoises	Coefficient of thermal conductivity, k, cal/(sec)(cm)(°K)	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.0; o/f = 5.743; percent fuel = 14.83											
4400	1179.7	2848.0	21.838	-.2021	1.1996	0.9105	1590	0.00163	-------	-------	-------
4000	592.07	2587.2	22.248	-.1893	1.1961	.8684	1474	.00144	4.015	0.106	20.3
3600	274.15	2328.7	22.683	-.1785	1.1903	.8418	1351	.00129	1.029	.785	151.4
3200	114.500	2071.5	23.142	-.1585	1.1858	.7944	1224	.00110	1.527	1.104	212.8
3000	71.518	1946.8	23.365	-.1362	1.1892	.7322	1160	.00097	2.039	1.229	236.9
2800	44.430	1829.9	23.563	-.1128	1.2000	.6573	1095	.00084	2.794	1.336	257.5
2600	26.212	1710.6	23.823	-.2283	1.1729	1.0050	1025	.00114	4.045	1.436	276.9
2400	11.395	1539.6	24.487	-.4313	1.1331	2.3226	936	.00227	7.648	1.570	302.6
2200	3.537	1326.1	25.523	-.5057	1.1160	3.3206	840	.00287	19.755	1.721	331.9
2000	.819	1093.1	26.815	-.5244	1.1046	3.6467	746	.00279	67.815	1.873	361.1
1800	.141	852.2	28.381	-.5068	1.0961	3.3413	658	.00226	312.080	2.018	389.1
1600	.018	616.6	29.954	-.4332	1.0982	2.4256	578	.00145	1880.5	2.150	414.6
1400	.002	417.1	31.378	-.2416	1.1067	1.1511	507	.00062	11620.	2.256	435.0
900	.000	198.6	32.013	-.0000	1.2463	.3142	357	.00014	138020	2.367	456.3
r = 1.4; o/f = 4.102; percent fuel = 19.60											
4800	1186.6	3341.1	20.775	-.2856	1.1757	1.3763	1653	0.00247	-------	-------	-------
4400	528.97	3012.7	21.284	-.2683	1.1697	1.2888	1559	.00219	1.432	0.321	67.4
4000	230.67	2691.3	21.804	-.2357	1.1674	1.1434	1459	.00183	1.090	.858	180.3
3600	95.692	2390.1	22.292	-.1812	1.1737	.9283	1350	.00140	1.720	1.154	242.3
3200	40.662	2132.7	22.660	-.0929	1.2058	.6357	1233	.00092	3.012	1.356	284.8
3000	27.800	2029.5	22.761	-.0460	1.2396	.5011	1172	.00071	3.901	1.429	300.2
2800	19.653	1941.7	22.806	-.0162	1.2744	.4195	1110	.00059	4.936	1.489	312.6
2600	14.036	1862.6	22.823	-.0065	1.2934	.3896	1047	.00052	6.198	1.540	323.4
2400	9.557	1779.2	22.876	-.0905	1.2273	.5804	980	.00068	8.106	1.593	334.5
2200	4.791	1642.8	23.266	-.2538	1.1564	1.1737	897	.00115	13.858	1.675	351.8
2000	1.987	1486.8	23.801	-.1992	1.1607	.9633	811	.00087	28.184	1.764	370.6
1800	.919	1365.0	24.131	-.0671	1.2176	.5357	735	.00047	52.145	1.831	384.6
1600	.506	1281.6	24.215	-.0078	1.2884	.3729	668	.00032	81.850	1.876	393.9
1400	.285	1210.8	24.223	-.0004	1.3119	.3454	600	.00027	124.91	1.913	401.7
1200	.150	1142.7	24.223	-.0000	1.3235	.3356	531	.00023	199.24	1.947	409.0
r = 1.5; o/f = 3.829; percent fuel = 20.71											
4800	1101.8	3445.0	20.544	-.2878	1.1734	1.4230	1636	0.00253	-------	-------	-------
4400	512.05	3108.4	21.053	-.2721	1.1675	1.3349	1544	.00224	1.313	0.359	76.1
4000	220.29	2778.3	21.576	-.2403	1.1646	1.1868	1446	.00188	1.110	.877	185.8
3600	89.635	2467.3	22.070	-.1866	1.1690	.9722	1340	.00145	1.796	1.172	248.1
3200	36.424	2194.0	22.464	-.1130	1.1889	.7209	1227	.00102	3.279	1.380	292.2
3000	23.768	2077.3	22.600	-.0742	1.2088	.6012	1168	.00083	4.426	1.459	309.1
2800	15.923	1975.3	22.687	-.0402	1.2378	.4985	1107	.00067	5.876	1.526	323.1
2600	10.864	1885.0	22.741	-.0311	1.2551	.4611	1043	.00060	7.693	1.582	335.0
2400	7.140	1793.5	22.814	-.0440	1.2437	.4907	976	.00058	10.409	1.637	346.7
2200	4.570	1704.3	22.884	-.0238	1.2662	.4354	907	.00049	14.405	1.689	357.7
2000	2.943	1624.1	22.915	-.0071	1.2956	.3860	839	.00041	19.775	1.735	367.4
1800	1.874	1549.7	22.923	-.0013	1.3138	.3640	771	.00036	27.298	1.776	376.1
1600	1.152	1478.1	22.925	-.0001	1.3248	.3537	701	.00032	38.626	1.814	384.3
1200	.366	1339.9	22.926	-.0006	1.3455	.3381	556	.00025	87.599	1.887	399.6
r = 1.6; o/f = 3.589; percent fuel = 21.79											
4400	604.93	3285.5	20.965	-.2703	1.1670	1.3538	1497	0.00220	-------	-------	-------
4000	260.94	2955.0	21.479	-.2343	1.1654	1.1806	1396	.00181	1.046	0.804	168.7
3600	99.836	2621.5	21.948	-.1776	1.1521	1.0671	1329	.00157	1.695	1.143	239.7
3200	38.634	2331.5	22.323	-.1087	1.1887	.7427	1242	.00106	3.191	1.371	287.6
2800	16.680	2108.0	22.544	-.0448	1.2321	.5178	1126	.00071	5.761	1.524	319.6
2400	7.650	1989.8	22.636	-.0135	1.2745	.4201	997	.00053	9.992	1.635	343.0
2000	3.375	1772.1	22.663	-.0025	1.3013	.3807	862	.00042	17.841	1.728	362.5
1600	1.318	1624.1	22.668	-.0002	1.3206	.3612	720	.00034	34.879	1.811	379.8
1200	.414	1483.0	22.669	-.0007	1.3412	.3451	569	.00026	79.838	1.886	395.7
900	.124	1373.8	22.773	-.0759	1.2423	.5296	450	.00029	192.75	1.943	407.5
r = 2.5; o/f = 2.297; percent fuel = 30.33											
4000	737.24	4208.2	20.326	-.1657	1.1677	1.0699	1563	0.00186	-------	-------	-------
3600	326.65	3908.2	20.651	-.1342	1.1816	.8848	1459	.00147	1.001	0.694	138.6
3200	142.10	3637.8	20.935	-.0972	1.1936	.7432	1335	.00115	1.353	1.036	206.7
2800	60.257	3394.9	21.150	-.0565	1.2102	.6181	1204	.00089	2.260	1.267	252.7
2400	24.973	3180.5	21.273	-.0222	1.2346	.5171	1066	.00068	4.089	1.440	287.3
2000	9.863	2990.1	21.318	-.0047	1.2598	.4568	923	.00053	7.856	1.578	314.8
1600	3.446	2814.8	21.327	-.0005	1.2789	.4277	772	.00042	16.734	1.695	338.2
1200	.952	2647.4	21.331	-.0020	1.2970	.4087	612	.00032	42.778	1.799	359.0
900	.240	2514.9	21.494	-.1082	1.2030	.7018	485	.00040	121.00	1.878	374.7

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TABLE III. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLOURINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Equilibrium composition during isentropic expansion or compression from combustion conditions.]

(b) Combustion-chamber pressure, 300 pounds per square inch absolute

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(^{\circ}K)}$	Coefficient of viscosity, μ, micropoises	Coefficient of thermal conductivity, k, cal/(sec)(cm)(°K)	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.00; o/f = 5.743; percent fuel = 14.83											
4000	355.88	2652.8	22.002	-.2058	1.1909	0.9365	1479	0.00155	-------	-------	-------
3600	160.57	2382.8	22.468	-.1931	1.1859	.8987	1357	.00137	1.002	0.705	134.9
3200	64.902	2113.7	22.967	-.1774	1.1793	.8631	1229	.00119	1.426	1.066	204.0
3000	39.476	1981.1	23.219	-.1593	1.1794	.8134	1164	.00107	1.924	1.205	230.5
2800	23.683	1854.9	23.450	-.1256	1.1881	.7123	1099	.00090	2.698	1.323	253.2
2600	14.427	1742.0	23.635	-.0961	1.2076	.6100	1034	.00074	3.800	1.421	272.0
2400	7.837	1615.0	23.971	-.3103	1.1513	1.3981	959	.00144	5.938	1.524	291.6
2200	2.686	1415.0	24.864	-.4905	1.1186	3.0738	862	.00274	13.952	1.678	320.0
2000	.628	1177.5	26.127	-.5373	1.1046	3.9044	764	.00306	47.066	1.833	350.8
1800	.104	925.4	27.655	-.5352	1.0947	3.8646	671	.00265	222.40	1.990	380.8
1600	.012	672.8	29.382	-.4826	1.0886	3.0324	586	.00183	1465.7	2.135	408.6
1400	.001	446.6	31.047	-.3196	1.0948	1.5860	510	.00085	11360.	2.258	432.1
900	.000	198.6	32.013	-.0001	1.2462	.3143	357	.00014	189140	2.385	456.3
r = 1.25; o/f = 4.595; percent fuel = 17.87											
4400	415.71	3025.0	21.237	-.2764	1.1718	1.3068	1572	0.00224	-------	-------	-------
4000	182.13	2704.9	21.773	-.2440	1.1700	1.1562	1469	.00187	1.003	0.631	128.2
3600	75.630	2403.8	22.288	-.1990	1.1743	.9708	1355	.00147	1.319	1.016	206.5
3200	30.534	2131.7	22.744	-.1436	1.1867	.7762	1232	.00109	2.282	1.266	257.5
3000	19.500	2010.7	22.928	-.1045	1.2016	.6561	1168	.00089	3.087	1.363	277.2
2800	12.795	1905.1	23.056	-.0568	1.2319	.5202	1105	.00069	4.127	1.442	293.3
2600	8.733	1816.3	23.119	-.0214	1.2713	.4225	1042	.00055	5.364	1.506	306.2
2400	5.882	1731.6	23.182	-.0923	1.2258	.5782	976	.00067	7.059	1.564	318.0
2200	2.661	1577.6	23.704	-.3802	1.1329	1.9238	889	.00180	13.145	1.664	338.4
2000	.774	1364.7	24.664	-.4252	1.1166	2.3678	791	.00195	36.654	1.794	364.8
1800	.188	1152.5	25.701	-.3352	1.1177	1.6736	700	.00124	122.25	1.914	389.3
1600	.055	992.9	26.401	-.1146	1.1676	.6783	624	.00048	345.41	2.000	406.7
1400	.025	904.8	26.553	-.0072	1.2655	.3623	560	.00026	640.54	2.046	416.0
900	.004	738.4	26.560	-.0000	1.3067	.3187	395	.00016	2803.7	2.130	433.1
r = 1.40; o/f = 4.102; percent fuel = 19.60											
4400	345.92	3123.8	20.936	-.2991	1.1649	1.4691	1553	0.00247	-------	-------	-------
4000	143.83	2778.9	21.514	-.2701	1.1605	1.3210	1455	.00209	1.021	0.758	157.7
3600	55.745	2450.7	22.080	-.2193	1.1628	1.0922	1349	.00163	1.576	1.111	231.2
3200	21.502	2162.2	22.551	-.1334	1.1843	.7706	1233	.00109	2.934	1.346	280.3
3000	13.942	2044.2	22.705	-.0773	1.2133	.5930	1172	.00082	3.962	1.432	298.0
2800	9.496	1946.8	22.787	-.0312	1.2547	.4605	1110	.00063	5.169	1.498	311.9
2600	6.677	1864.0	22.817	-.0086	1.2880	.3970	1047	.00053	6.578	1.553	323.3
2400	4.690	1787.1	22.828	-.0097	1.2943	.3914	982	.00049	8.377	1.602	333.4
2200	2.823	1686.3	22.994	-.2021	1.1718	.9549	909	.00097	12.193	1.664	346.3
2000	1.141	1524.1	23.557	-.2551	1.1466	1.2156	820	.00108	25.325	1.759	366.2
1800	.455	1378.2	24.043	-.1199	1.1834	.6994	738	.00059	53.492	1.840	383.1
1600	.231	1283.1	24.205	-.0168	1.2727	.3975	668	.00033	90.474	1.892	393.8
1400	.129	1210.8	24.222	-.0008	1.3108	.3466	600	.00027	139.49	1.930	401.7
1200	.068	1142.7	24.223	-.0000	1.3235	.3356	531	.00023	222.60	1.965	409.0
900	.021	1044.2	24.223	-.0000	1.3427	.3814	421	.00018	514.81	2.014	419.3
r = 1.50; o/f = 3.829; percent fuel = 20.71											
4400	336.20	3222.7	20.704	-.3028	1.1630	1.5214	1537	0.00258	-------	-------	-------
4000	137.93	2868.8	21.285	-.2757	1.1581	1.3750	1441	.00215	1.031	0.778	163.2
3600	52.404	2530.2	21.858	-.2250	1.1591	1.1417	1337	.00168	1.640	1.129	236.9
3200	19.503	2228.0	22.346	-.1468	1.1739	.8422	1226	.00117	3.161	1.368	287.1
3000	12.168	2098.4	22.525	-.1016	1.1911	.6915	1167	.00094	4.419	1.458	306.1
2800	7.837	1986.2	22.649	-.0584	1.2189	.5562	1107	.00074	6.061	1.532	321.6
2600	5.241	1890.9	22.716	-.0288	1.2546	.4606	1044	.00060	8.074	1.593	334.3
2400	3.490	1808.2	22.773	-.0424	1.2452	.4872	978	.00058	10.796	1.647	345.6
2200	2.196	1709.4	22.859	-.0353	1.2515	.4678	908	.00052	15.167	1.701	357.1
2000	1.386	1625.5	22.908	-.0117	1.2867	.3994	839	.00043	21.198	1.749	367.2
1800	.876	1550.0	22.922	-.0023	1.3115	.3668	771	.00037	29.452	1.792	376.0
1600	.538	1478.1	22.924	-.0003	1.3245	.3540	701	.00032	41.728	1.831	384.3
1200	.171	1339.9	22.925	-.0003	1.3460	.3374	556	.00025	94.615	1.904	399.6
900	.055	1237.1	22.974	-.0383	1.2902	.4184	439	.00023	215.61	1.956	410.6
r = 1.60; o/f = 3.589; percent fuel = 21.79											
4400	400.04	3401.8	20.605	-.3030	1.1624	1.5564	1497	0.00251	-------	-------	-------
4000	163.96	3045.7	21.181	-.2723	1.1581	1.3849	1396	.00210	1.002	0.690	143.4
3600	58.772	2685.4	21.735	-.2171	1.1435	1.2593	1324	.00182	1.543	1.096	227.8
3200	20.764	2365.2	22.202	-.1413	1.1686	.8646	1241	.00121	3.065	1.358	282.5
2800	8.296	2120.1	22.495	-.0611	1.2172	.5687	1126	.00076	5.885	1.529	318.0
2400	3.663	1932.9	22.622	-.0189	1.2666	.4353	997	.00054	10.542	1.648	342.6
2000	1.595	1772.5	22.661	-.0035	1.2990	.3839	862	.00043	19.045	1.743	362.4
1600	.621	1624.1	22.668	-.0003	1.3204	.3615	720	.00034	37.323	1.826	379.8
1200	.195	1483.0	22.669	-.0003	1.3418	.3444	569	.00026	85.411	1.903	395.7
900	.062	1377.9	22.721	-.0413	1.2835	.4338	449	.00024	197.03	1.957	407.0

TABLE III. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED TEMPERATURES FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Equilibrium composition during isentropic expansion or compression from combustion conditions.]

(b) Concluded. Combustion-chamber pressure, 300 pounds per square inch absolute

Temperature, T, °K	Pressure, P, lb/sq in. abs	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Coefficient of viscosity, μ, micropoises	Coefficient of thermal conductivity, k, $\frac{cal}{(cm)(°K)(sec)}$	Area ratio, ε	Thrust coefficient, C_F	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.75; o/f = 3.282; percent fuel = 23.35											
4400	539.43	3679.3	20.444	-.2007	1.1664	1.4655	1487	0.00286	------	------	------
4000	195.81	3271.5	20.970	-.2533	1.1354	1.5939	1413	.00248	1.015	0.580	180.1
3600	69.489	2902.6	21.483	-.2011	1.1523	1.1614	1361	.00174	1.400	1.041	215.7
3200	26.466	2601.8	21.903	-.1286	1.1816	.8022	1262	.00116	2.863	1.301	269.6
2800	10.941	2363.5	22.186	-.0688	1.2163	.5900	1140	.00080	4.782	1.476	308.8
2400	4.679	2165.7	22.349	-.0266	1.2528	.4678	1009	.00058	8.640	1.605	332.6
2000	1.966	1996.5	22.399	-.0055	1.2875	.4021	872	.00045	16.054	1.709	354.1
1600	.747	1842.4	22.409	-.0004	1.3111	.3740	729	.00035	38.122	1.798	378.5
1200	.229	1696.5	22.410	-.0004	1.3324	.3558	577	.00027	75.150	1.878	389.2
900	.070	1587.7	22.468	-.0450	1.2733	.4553	455	.00026	177.86	1.936	401.2
r = 2.00; o/f = 2.872; percent fuel = 25.83											
4400	676.30	4018.8	20.181	-.2574	1.1388	1.8382	1494	0.00293	------	------	------
4000	254.73	3619.0	20.629	-.2304	1.1484	1.4251	1476	.00228	1.294	0.363	74.4
3600	98.689	3275.3	21.082	-.1808	1.1650	1.0550	1400	.00164	1.164	.919	188.3
3200	39.706	2986.3	21.467	-.1276	1.1860	.8048	1288	.00119	1.930	1.201	246.2
2800	16.227	2739.5	21.760	-.0764	1.2084	.6330	1162	.00087	3.503	1.398	286.5
2400	6.673	2529.4	21.935	-.0311	1.2400	.5028	1028	.00063	6.550	1.546	316.8
2000	2.702	2349.7	22.000	-.0065	1.2744	.4256	889	.00048	12.508	1.663	340.6
1600	.992	2187.3	22.013	-.0005	1.2983	.3934	743	.00036	25.704	1.760	360.7
1200	.293	2034.0	22.014	-.0006	1.3190	.3737	589	.00029	62.154	1.848	378.8
900	.086	1919.2	22.081	-.0518	1.2587	.4909	465	.00026	153.07	1.911	391.7
r = 2.50; o/f = 2.297; percent fuel = 30.33											
4000	449.38	4284.4	20.076	-.1965	1.1604	1.2316	1559	0.00211	------	------	------
3600	188.74	3961.2	20.460	-.1686	1.1736	1.0016	1457	.00164	1.009	0.609	120.8
3200	77.784	3671.0	20.807	-.1226	1.1845	.8300	1335	.00127	1.295	1.006	199.6
2800	31.236	3411.5	21.083	-.0752	1.2003	.6749	1203	.00095	2.284	1.259	249.5
2400	12.395	3188.9	21.251	-.0309	1.2268	.5488	1066	.00070	4.158	1.444	286.4
2000	4.793	2991.0	21.314	-.0067	1.2568	.4630	923	.00053	8.133	1.586	314.7
1600	1.667	2814.3	21.327	-.0005	1.2786	.4281	772	.00042	17.400	1.705	338.2
1200	.461	2647.6	21.329	-.0010	1.2980	.4068	612	.00032	44.445	1.809	359.0
900	.125	2521.4	21.417	-.0646	1.2352	.5640	484	.00033	117.64	1.885	374.0
r = 3.00; o/f = 1.914; percent fuel = 34.31											
3600	332.18	4560.1	19.998	-.1455	1.1755	0.9754	1507	0.00166	------	------	------
3200	138.50	4267.0	20.302	-.1100	1.1831	.8325	1379	.00132	1.027	0.778	149.5
2800	55.542	4000.4	20.543	-.0669	1.1965	.6908	1243	.00101	1.658	1.111	213.4
2400	21.722	3765.3	20.688	-.0274	1.2194	.5687	1102	.00076	2.806	1.337	256.9
2000	8.148	3558.6	20.743	-.0060	1.2448	.4936	954	.00059	5.512	1.509	289.8
1600	2.712	3369.5	20.754	-.0005	1.2642	.4588	799	.00046	12.107	1.650	316.9
1200	.710	3190.9	20.758	-.0016	1.2823	.4365	634	.00035	32.881	1.773	340.6
900	.178	3053.9	20.872	-.0802	1.2162	.6438	503	.00038	91.316	1.868	357.7
r = 4.00; o/f = 1.436; percent fuel = 41.05											
3200	378.98	5267.2	19.536	-.0821	1.1817	0.8151	1459	0.00137	------	------	------
2800	153.44	4992.7	19.707	-.0486	1.1927	.7026	1316	.00109	1.007	0.789	131.8
2400	59.237	4744.0	19.807	-.0198	1.2099	.6088	1168	.00085	1.485	1.092	197.5
2000	21.883	4518.7	19.846	-.0044	1.2285	.5438	1013	.00068	2.804	1.339	242.1
1600	6.622	4309.0	19.854	-.0007	1.2443	.5108	849	.00054	6.894	1.533	277.3
1200	1.586	4109.9	19.862	-.0038	1.2600	.4897	678	.00042	17.794	1.697	306.9
900	.343	3951.9	20.049	-.1161	1.1880	.8250	538	.00051	57.043	1.816	328.5

TABLE IV. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 1 TO 8 FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Equilibrium composition during isentropic expansion.]

(a) Combustion-chamber pressure, 600 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{P_c/P}$	Enthalpy, h, cal/g	Molecular weight, $\bar{M}$	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_P$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_S$	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Area ratio, ϵ	Area-ratio exponent, n_ϵ, $\left(\frac{\partial \ln \epsilon}{\partial \ln P_c}\right)_{P_c/P}$	Thrust coefficient, C_F	Specific-impulse exponent, n_I, $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{P_c/P}$	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.0; o/f = 5.743; percent fuel = 14.83													
1.000	600.00	4007	0.0351	2592.0	22.24	-.189	1.194	0.869	------	------	------	------	------
1.020	588.24	3996	.0349	2584.9	22.25	-.189	1.196	.868	3.310	0.0024	0.129	0.0130	24.6
1.040	576.92	3986	.0348	2578.0	22.26	-.190	1.196	.867	2.392	.0025	.181	.0130	34.9
1.200	500.00	3908	.0337	2527.6	22.35	-.187	1.195	.862	1.252	.0017	.388	.0128	74.0
1.472	407.61	3800	.0323	2457.8	22.46	-.184	1.193	.855	1.034	.0008	.560	.0125	108.0
[a]1.766	339.67	3706	.0310	2397.4	22.56	-.182	1.192	.849	1.000	.0001	.675	.0122	130.1
2.208	271.73	3596	.0295	2325.9	22.69	-.179	1.190	.842	1.031	-.0009	.789	.0119	152.2
4.000	150.00	3319	.0249	2147.3	23.01	-.167	1.186	.816	1.315	-.0038	1.020	.0111	196.7
8.000	75.00	3020	.0185	1959.0	23.34	-.138	1.189	.739	1.972	-.0082	1.217	.0101	234.7
r = 1.4; o/f = 4.102; percent fuel = 19.60													
1.000	600.00	4464	0.0428	3064.9	21.20	-.272	1.171	1.306	------	------	------	------	------
1.020	588.24	4454	.0426	3056.6	21.21	-.271	1.170	1.304	3.285	0.0029	0.128	0.0155	26.5
1.040	576.92	4444	.0424	3048.5	21.23	-.270	1.170	1.301	2.375	.0027	.180	.0155	37.7
1.200	500.00	4372	.0412	2989.6	21.32	-.267	1.169	1.281	1.251	.0021	.385	.0152	80.9
1.460	411.02	4275	.0394	2910.9	21.45	-.261	1.168	1.250	1.035	.0011	.551	.0149	115.6
[a]1.752	342.50	4187	.0377	2839.6	21.56	-.258	1.168	1.219	1.000	-.0000	.667	.0146	140.0
2.190	274.01	4080	.0357	2754.9	21.70	-.244	1.167	1.178	1.032	-.0013	.782	.0142	164.2
4.000	150.00	3803	.0293	2539.2	22.05	-.212	1.168	1.047	1.328	-.0052	1.016	.0131	213.9
8.000	75.00	3490	.0203	2313.3	22.41	-.159	1.178	.850	2.005	-.0111	1.218	.0118	255.7
r = 1.6; o/f = 3.829; percent fuel = 20.71													
1.000	600.00	4479	0.0431	3175.0	20.95	-.276	1.169	1.357	------	------	------	------	------
1.020	588.24	4469	.0429	3166.6	20.96	-.275	1.168	1.354	3.283	0.0027	0.128	0.0156	27.0
1.040	576.92	4460	.0427	3158.4	20.98	-.276	1.168	1.352	2.374	.0029	.180	.0155	38.0
1.200	500.00	4388	.0415	3098.5	21.07	-.271	1.167	1.331	1.251	.0019	.385	.0153	81.6
1.459	411.36	4293	.0398	3018.9	21.19	-.265	1.166	1.302	1.035	.0009	.550	.0150	116.6
[a]1.750	342.80	4205	.0381	2946.4	21.31	-.258	1.165	1.271	1.000	-.0002	.666	.0147	141.0
2.188	274.24	4101	.0361	2860.3	21.44	-.251	1.165	1.230	1.032	-.0012	.781	.0143	165.5
4.000	150.00	3827	.0300	2640.5	21.80	-.219	1.165	1.101	1.329	-.0051	1.018	.0132	215.7
8.000	75.00	3522	.0219	2410.3	22.16	-.173	1.171	.924	2.018	-.0102	1.215	.0119	258.0
r = 1.8; o/f = 3.589; percent fuel = 21.79													
1.000	600.00	4396	0.0426	3282.1	20.97	-.270	1.167	1.351	------	------	------	------	------
1.020	588.24	4386	.0426	3273.8	20.98	-.270	1.168	1.344	3.289	0.0027	0.128	0.0152	26.8
1.040	576.92	4377	.0425	3265.8	21.00	-.269	1.168	1.338	2.373	.0027	.180	.0151	37.7
1.200	500.00	4307	.0417	3207.1	21.09	-.263	1.170	1.297	1.251	.0021	.385	.0149	80.8
1.459	411.39	4213	.0401	3129.0	21.21	-.256	1.170	1.251	1.035	.0012	.550	.0145	115.4
[a]1.750	342.81	4127	.0381	3057.9	21.32	-.248	1.169	1.216	1.000	-.0000	.666	.0142	139.6
2.188	274.26	4023	.0354	2973.4	21.48	-.236	1.166	1.187	1.032	-.0018	.781	.0138	163.9
4.000	150.00	3764	.0276	2757.7	21.77	-.204	1.156	1.123	1.335	-.0064	1.018	.0124	213.6
8.000	75.00	3453	.0206	2530.0	22.07	-.158	1.158	.978	2.034	-.0111	1.220	.0109	255.8
r = 2.8; o/f = 2.297; percent fuel = 30.33													
1.000	600.00	3898	0.0308	4128.2	20.41	-.159	1.172	1.017	------	------	------	------	------
1.020	588.24	3889	.0307	4121.3	20.42	-.158	1.172	1.018	3.294	0.0024	0.128	0.0100	22.6
1.040	576.92	3879	.0305	4114.0	20.43	-.158	1.172	1.008	2.381	.0023	.180	.0100	35.9
1.200	500.00	3809	.0294	4060.6	20.49	-.151	1.172	.974	1.254	.0016	.386	.0098	77.1
1.467	408.97	3710	.0276	3987.4	20.56	-.144	1.176	.930	1.034	.0010	.556	.0095	110.9
[a]1.761	340.81	3621	.0258	3922.9	20.63	-.137	1.181	.893	1.000	.0001	.671	.0093	133.8
2.201	272.65	3512	.0236	3846.5	20.72	-.127	1.184	.851	1.031	-.0011	.786	.0089	156.7
4.000	150.00	3226	.0174	3684.3	20.92	-.100	1.193	.781	1.315	-.0046	1.018	.0080	203.2
8.000	75.00	2901	.0095	3453.6	21.10	-.066	1.205	.648	1.966	-.0094	1.215	.0069	242.4

[a]At throat.

[redacted]

TABLE IV. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 1 TO 8 FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Equilibrium composition during isentropic expansion]

(b) Combustion-chamber pressure, 300 pounds per square inch absolute

Pressure ratio, P_o/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{\frac{P_o}{P}}$	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Area ratio, ε	Area-ratio exponent, n_ε, $\left(\frac{\partial \ln \varepsilon}{\partial \ln P_c}\right)_{\frac{P_o}{P}}$	Thrust coefficient, C_F	Specific-impulse exponent, n_I, $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{\frac{P_o}{P}}$	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.00; o/f = 5.743; percent fuel = 14.83													
1.000	300.00	3910	0.0358	2592.0	22.10	-.202	1.190	0.924	------	-------	------	-------	------
1.020	294.11	3900	.0356	2585.0	22.12	-.201	1.190	.923	3.304	0.0083	0.189	0.0134	24.6
1.040	288.47	3890	.0355	2578.2	22.13	-.200	1.190	.922	2.388	.0082	.181	.0134	34.6
1.200	250.00	3817	.0345	2528.8	22.21	-.199	1.189	.914	1.256	.0017	.387	.0132	74.1
1.469	204.20	3716	.0331	2460.8	22.33	-.196	1.188	.906	1.034	.0008	.558	.0129	106.8
[a]1.763	170.16	3628	.0318	2401.4	22.44	-.194	1.186	.900	1.000	-.0000	.673	.0126	128.8
2.204	136.13	3523	.0302	2330.9	22.56	-.191	1.184	.894	1.031	-.0011	.788	.0123	150.7
4.000	75.00	3260	.0261	2154.2	22.89	-.181	1.180	.878	1.319	-.0036	1.020	.0118	195.2
8.000	37.50	2980	.0201	1968.0	23.24	-.156	1.180	.805	1.988	-.0076	1.218	.0105	233.0
r = 1.25; o/f = 4.595; percent fuel = 17.87													
1.000	300.00	4238	0.0411	2893.9	21.45	-.265	1.171	1.251	------	-------	------	-------	------
1.020	294.11	4228	.0410	2886.1	21.47	-.264	1.170	1.248	3.287	0.0030	0.128	0.0152	26.0
1.040	288.47	4219	.0408	2878.5	21.48	-.263	1.170	1.244	2.376	.0029	.180	.0152	36.6
1.200	250.00	4150	.0398	2823.3	21.57	-.258	1.170	1.218	1.252	.0022	.386	.0149	78.4
1.461	205.32	4066	.0378	2749.1	21.70	-.249	1.170	1.180	1.034	.0009	.558	.0146	112.3
[a]1.753	171.11	3971	.0361	2682.2	21.81	-.240	1.170	1.144	1.000	-.0001	.667	.0142	138.7
2.192	136.88	3868	.0341	2602.8	21.95	-.231	1.171	1.098	1.032	-.0013	.783	.0138	159.2
4.000	75.00	3596	.0283	2401.1	22.29	-.198	1.174	.969	1.325	-.0051	1.018	.0127	207.1
8.000	37.50	3290	.0207	2190.1	22.68	-.158	1.188	.824	1.997	-.0098	1.217	.0114	247.5
r = 1.40; o/f = 4.102; percent fuel = 19.60													
1.000	300.00	4332	0.0437	3064.9	21.03	-.295	1.164	1.449	------	-------	------	-------	------
1.020	294.11	4323	.0436	3056.8	21.05	-.294	1.164	1.446	3.279	0.0028	0.127	0.0160	26.5
1.040	288.47	4314	.0434	3048.9	21.06	-.293	1.164	1.443	2.371	.0027	.179	.0160	37.3
1.200	250.00	4247	.0423	2991.2	21.15	-.289	1.163	1.420	1.250	.0021	.385	.0157	80.1
1.456	205.99	4159	.0407	2915.0	21.28	-.283	1.162	1.388	1.035	.0010	.549	.0154	114.2
[a]1.748	171.66	4078	.0390	2845.1	21.40	-.276	1.161	1.355	1.000	-.0001	.664	.0151	138.3
2.184	137.33	3980	.0369	2761.9	21.54	-.268	1.160	1.318	1.032	-.0013	.780	.0147	162.4
4.000	75.00	3723	.0318	2548.9	21.91	-.238	1.161	1.173	1.332	-.0048	1.016	.0137	211.9
8.000	37.50	3436	.0227	2325.5	22.29	-.190	1.167	.970	2.020	-.0099	1.216	.0124	253.6
r = 1.50; o/f = 3.829; percent fuel = 20.71													
1.000	300.00	4346	0.0439	3175.0	20.78	-.301	1.162	1.507	------	-------	------	-------	------
1.020	294.11	4337	.0438	3166.8	20.79	-.300	1.162	1.504	3.277	0.0028	0.127	0.0161	26.7
1.040	288.47	4328	.0436	3158.7	20.81	-.299	1.162	1.502	2.369	.0028	.179	.0160	37.6
1.200	250.00	4262	.0425	3100.2	20.90	-.296	1.161	1.481	1.249	.0020	.384	.0158	80.7
1.455	206.16	4175	.0409	3023.0	21.03	-.290	1.160	1.450	1.035	.0009	.548	.0155	115.0
[a]1.746	171.80	4095	.0394	2958.0	21.15	-.285	1.159	1.418	1.000	.0000	.664	.0152	139.3
2.183	137.44	3998	.0374	2867.4	21.29	-.276	1.158	1.374	1.032	-.0012	.779	.0148	163.6
4.000	75.00	3746	.0318	2650.4	21.65	-.247	1.158	1.236	1.334	-.0046	1.018	.0138	213.6
8.000	37.50	3465	.0243	2423.1	22.04	-.201	1.162	1.045	2.026	-.0096	1.219	.0126	255.8
r = 1.60; o/f = 3.589; percent fuel = 21.79													
1.000	300.00	4267	0.0442	3282.1	20.60	-.295	1.164	1.479	------	-------	------	-------	------
1.020	294.11	4258	.0441	3274.0	20.61	-.295	1.164	1.475	3.276	0.0034	0.127	0.0157	26.5
1.040	288.47	4249	.0439	3266.1	20.62	-.294	1.164	1.471	2.369	.0033	.179	.0157	37.3
1.200	250.00	4185	.0427	3208.6	20.91	-.290	1.163	1.443	1.249	.0026	.384	.0154	79.9
1.455	206.20	4099	.0408	3133.1	21.04	-.282	1.161	1.413	1.035	.0013	.548	.0151	113.9
[a]1.746	171.83	4020	.0388	3063.3	21.15	-.274	1.159	1.390	1.000	-.0000	.663	.0148	138.0
2.182	137.46	3926	.0363	2980.3	21.29	-.264	1.155	1.367	1.033	-.0018	.779	.0144	162.0
4.000	75.00	3691	.0295	2766.9	21.61	-.232	1.145	1.300	1.341	-.0060	1.015	.0130	211.7
8.000	37.50	3431	.0231	2541.7	21.95	-.186	1.150	1.102	2.049	-.0101	1.221	.0116	253.8

[a]At throat.

[redacted]

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TABLE IV. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 1 TO 8 FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Equilibrium composition during isentropic expansion]

(b) Concluded. Combustion-chamber pressure, 300 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Area ratio, ε	Area-ratio exponent, $n_ε$, $\left(\frac{\partial \ln ε}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Thrust coefficient, C_F	Specific-impulse exponent, n_I, $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.75; o/f = 3.282; percent fuel = 23.35													
1.000	300.00	4163	0.0391	3437.3	20.76	-.267	1.141	1.641	--------	--------	------	--------	------
1.020	294.11	4150	.0389	3429.5	20.77	-.266	1.140	1.642	3.246	0.0031	0.126	0.0116	26.2
1.040	288.47	4143	.0387	3421.7	20.78	-.265	1.140	1.642	2.348	.0030	.178	.0116	36.8
1.200	250.00	4090	.0372	3365.4	20.85	-.261	1.137	1.636	1.242	.0020	.382	.0114	79.1
1.444	207.71	4022	.0356	3293.9	20.94	-.255	1.136	1.607	1.036	.0011	.539	.0114	111.7
[a]1.733	173.09	3953	.0342	3225.0	21.03	-.248	1.136	1.560	1.000	.0000	.656	.0114	135.9
2.167	138.47	3868	.0328	3142.8	21.14	-.240	1.137	1.482	1.033	-.0009	.773	.0113	160.1
4.000	75.00	3630	.0284	2928.2	21.45	-.206	1.150	1.199	1.342	-.0032	1.016	.0109	210.5
8.000	37.50	3349	.0217	2705.7	21.76	-.155	1.170	.921	2.036	-.0077	1.218	.0101	232.3
r = 2.00; o/f = 2.872; percent fuel = 25.83													
1.000	300.00	4067	0.0362	3682.7	20.55	-.237	1.143	1.494	--------	--------	------	--------	------
1.020	294.11	4059	.0361	3674.9	20.56	-.237	1.143	1.486	3.265	0.0018	0.127	0.0119	26.0
1.040	288.47	4051	.0360	3667.3	20.57	-.236	1.143	1.477	2.361	.0017	.179	.0119	36.6
1.200	250.00	3992	.0352	3611.8	20.64	-.230	1.146	1.417	1.247	.0014	.383	.0118	78.5
1.453	206.49	3913	.0341	3539.2	20.73	-.221	1.149	1.338	1.035	.0007	.545	.0116	111.7
[a]1.743	172.08	3837	.0330	3471.6	20.82	-.212	1.153	1.264	1.000	-.0000	.661	.0115	135.5
2.179	137.66	3743	.0313	3391.1	20.93	-.200	1.158	1.177	1.032	-.0008	.777	.0112	159.3
4.000	75.00	3481	.0257	3184.2	21.21	-.166	1.171	.970	1.330	-.0039	1.016	.0104	208.3
8.000	37.50	3175	.0182	2969.4	21.49	-.124	1.187	.792	2.001	-.0087	1.216	.0094	249.1
r = 2.50; o/f = 2.297; percent fuel = 30.33													
1.000	300.00	3813	0.0332	4128.8	20.26	-.181	1.167	1.114	--------	--------	------	--------	------
1.020	294.11	3804	.0331	4121.4	20.27	-.180	1.168	1.109	3.288	0.0024	0.128	0.0110	25.4
1.040	288.47	3795	.0329	4114.2	20.28	-.180	1.168	1.104	2.377	.0023	.180	.0109	35.7
1.200	250.00	3729	.0318	4061.5	20.34	-.174	1.170	1.067	1.253	.0017	.386	.0108	76.5
1.464	204.94	3638	.0300	3990.1	20.42	-.166	1.173	1.020	1.034	.0009	.554	.0105	109.9
[a]1.757	170.78	3554	.0283	3926.5	20.50	-.158	1.175	.980	1.000	.0001	.669	.0102	132.7
2.196	136.62	3453	.0262	3850.9	20.59	-.149	1.177	.934	1.031	-.0010	.784	.0099	155.5
4.000	75.00	3184	.0202	3659.9	20.82	-.121	1.185	.823	1.319	-.0046	1.018	.0090	202.0
8.000	37.50	2880	.0121	3460.4	21.04	-.085	1.196	.704	1.979	-.0093	1.215	.0078	241.2
r = 3.00; o/f = 1.914; percent fuel = 34.31													
1.000	300.00	3552	0.0277	4523.9	20.04	-.142	1.176	0.959	--------	--------	------	--------	------
1.020	294.11	3543	.0276	4517.0	20.04	-.141	1.176	.956	3.295	0.0026	0.128	0.0093	24.6
1.040	288.47	3534	.0274	4510.2	20.05	-.141	1.176	.952	2.382	.0027	.180	.0092	34.6
1.200	250.00	3468	.0261	4460.6	20.10	-.135	1.178	.929	1.254	.0020	.386	.0090	74.3
1.467	204.51	3376	.0242	4392.7	20.17	-.127	1.179	.896	1.034	.0010	.556	.0087	106.8
[a]1.760	170.41	3293	.0224	4333.0	20.24	-.119	1.181	.866	1.000	-.0001	.671	.0084	128.9
2.200	136.33	3193	.0201	4262.0	20.31	-.110	1.183	.830	1.031	-.0012	.786	.0081	151.0
4.000	75.00	2930	.0138	4083.8	20.47	-.082	1.191	.736	1.316	-.0048	1.019	.0071	195.7
8.000	37.50	2631	.0064	3897.4	20.62	-.048	1.205	.635	1.968	-.0093	1.215	.0059	233.5
r = 4.00; o/f = 1.436; percent fuel = 41.05													
1.000	300.00	3095	0.0153	5192.5	19.59	-.073	1.184	0.785	--------	--------	------	--------	------
1.020	294.11	3086	.0152	5186.3	19.59	-.072	1.184	.782	3.304	0.0025	0.128	0.0053	23.2
1.040	288.47	3077	.0150	5180.2	19.60	-.072	1.184	.780	2.388	.0024	.181	.0053	32.7
1.200	250.00	3013	.0137	5136.1	19.62	-.066	1.186	.762	1.257	.0018	.387	.0050	70.1
1.472	203.77	2983	.0119	5074.7	19.66	-.059	1.188	.736	1.033	.0009	.560	.0047	101.3
[a]1.767	169.81	2844	.0104	5021.6	19.69	-.052	1.191	.714	1.000	-.0000	.674	.0045	122.0
2.208	135.85	2748	.0087	4958.7	19.72	-.045	1.195	.689	1.031	-.0009	.789	.0041	142.6
4.000	75.00	2497	.0042	4802.0	19.79	-.025	1.205	.627	1.309	-.0035	1.019	.0033	184.3
8.000	37.50	2217	.0004	4638.3	19.83	-.011	1.218	.573	1.946	-.0054	1.214	.0025	219.6

[a]At throat.

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TABLE V. - THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO 1500 FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLOURINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Equilibrium composition during isentropic expansion]

(a) Combustion-chamber pressure, 600 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(^{\circ}K)}$	Area ratio, ε	Area-ratio exponent, n_ε, $\left(\frac{\partial \ln \varepsilon}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Thrust coefficient, C_F	Specific-impulse exponent, n_I, $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.0; o/f = 5.743; percent fuel = 14.83													
10	60.00	2926	0.0151	1902.7	23.44	-.121	1.194	0.687	2.29	-.0105	1.270	0.0097	244.9
15	40.00	2756	.0167	1805.3	23.61	-.128	1.197	.698	3.00	-.0099	1.357	.0091	261.6
20	30.00	2645	.0271	1740.1	23.74	-.192	1.182	.876	3.67	-.0033	1.412	.0088	272.2
30	20.00	2524	.0387	1653.0	24.02	-.297	1.155	1.380	4.95	.0031	1.483	.0089	285.8
40	15.00	2456	.0423	1594.1	24.25	-.370	1.141	1.852	6.17	.0055	1.528	.0091	294.7
60	10.00	2375	.0437	1514.4	24.60	-.444	1.130	2.485	8.48	.0070	1.588	.0094	306.2
80	7.50	2322	.0434	1460.1	24.85	-.474	1.125	2.788	10.68	.0067	1.628	.0096	313.8
100	6.00	2284	.0430	1419.2	25.05	-.490	1.122	2.975	12.80	.0062	1.657	.0098	319.5
150	4.00	2219	.0422	1347.3	25.41	-.504	1.117	3.254	17.85	.0047	1.707	.0099	329.1
200	3.00	2175	.0416	1298.1	25.67	-.511	1.114	3.401	22.65	.0037	1.740	.0100	335.5
300	2.00	2117	.0403	1231.2	26.03	-.520	1.111	3.546	31.80	.0023	1.785	.0101	344.1
400	1.50	2078	.0394	1185.4	26.28	-.523	1.108	3.608	40.53	.0011	1.815	.0102	349.8
600	1.00	2025	.0382	1122.9	26.64	-.524	1.106	3.646	57.20	-.0008	1.854	.0102	357.5
800	.75	1989	.0373	1080.0	26.89	-.524	1.104	3.647	73.15	-.0013	1.881	.0102	362.7
1000	.60	1962	.0365	1047.6	27.09	-.524	1.103	3.641	88.60	-.0020	1.901	.0102	366.6
1500	.40	1914	.0351	990.3	27.44	-.522	1.100	3.599	125.7	-.0034	1.936	.0101	373.3
r = 1.4; o/f = 4.102; percent fuel = 19.60													
10	60.00	3387	0.0163	2245.4	22.51	-.137	1.185	0.774	2.32	-.0135	1.271	0.0113	267.0
15	40.00	3192	.0083	2128.1	22.67	-.090	1.207	.629	3.05	-.0196	1.359	.0103	285.5
20	30.00	3042	.0003	2049.6	22.74	-.055	1.232	.525	3.70	-.0251	1.415	.0095	297.2
30	20.00	2810	-.0111	1946.0	22.81	-.017	1.273	.423	4.88	-.0331	1.486	.0083	312.0
40	15.00	2639	-.0172	1877.7	22.82	-.003	1.293	.385	5.92	-.0363	1.530	.0074	321.4
60	10.00	2419	.0071	1788.7	22.86	-.078	1.237	.549	7.84	-.0190	1.587	.0065	333.2
80	7.50	2315	.0226	1729.7	22.99	-.154	1.195	.788	9.73	-.0089	1.623	.0063	340.9
100	6.00	2254	.0272	1685.7	23.12	-.210	1.173	.992	11.59	-.0044	1.649	.0064	346.4
150	4.00	2158	.0250	1609.3	23.38	-.260	1.150	1.195	16.01	-.0027	1.695	.0065	355.9
200	3.00	2093	.0217	1557.5	23.56	-.248	1.148	1.148	20.20	-.0049	1.724	.0065	362.2
300	2.00	2001	.0182	1487.9	23.80	-.200	1.160	.967	28.04	-.0101	1.764	.0065	370.4
400	1.50	1933	.0139	1440.7	23.94	-.151	1.176	.806	35.36	-.0161	1.790	.0064	375.9
600	1.00	1825	-.0021	1377.7	24.11	-.080	1.209	.578	48.80	-.0278	1.824	.0061	383.2
800	.75	1736	-.0141	1335.5	24.18	-.042	1.243	.464	60.95	-.0369	1.847	.0058	387.9
1000	.60	1660	-.0227	1304.4	24.20	-.020	1.270	.405	72.13	-.0433	1.864	.0055	391.4
1500	.40	1517	-.0347	1251.5	24.22	-.008	1.302	.352	97.34	-.0499	1.891	.0049	397.2
r = 1.5; o/f = 3.829; percent fuel = 20.71													
10	60.00	3424	0.0188	2340.9	22.26	-.155	1.175	0.862	2.33	-.0121	1.272	0.0115	269.4
15	40.00	3243	.0127	2220.7	22.43	-.121	1.186	.747	3.07	-.0161	1.361	.0106	288.2
20	30.00	3110	.0076	2139.9	22.53	-.095	1.197	.666	3.76	-.0197	1.417	.0100	300.1
30	20.00	2916	-.0004	2032.4	22.64	-.058	1.221	.552	5.00	-.0255	1.489	.0090	315.3
40	15.00	2769	-.0065	1960.8	22.70	-.038	1.242	.489	6.13	-.0295	1.535	.0083	325.0
60	10.00	2558	-.0081	1866.3	22.75	-.034	1.253	.466	8.16	-.0303	1.593	.0074	337.4
80	7.50	2422	-.0058	1803.9	22.80	-.044	1.245	.488	10.04	-.0279	1.631	.0068	345.4
100	6.00	2322	-.0073	1757.8	22.85	-.038	1.250	.475	11.82	-.0293	1.658	.0064	351.2
150	4.00	2140	-.0144	1679.2	22.90	-.018	1.275	.419	15.86	-.0343	1.703	.0058	360.8
200	3.00	2009	-.0189	1627.4	22.91	-.008	1.294	.388	19.50	-.0373	1.733	.0053	367.0
300	2.00	1828	-.0219	1560.0	22.92	-.002	1.312	.366	26.06	-.0392	1.770	.0046	374.9
400	1.50	1706	-.0228	1515.9	22.92	-.000	1.320	.358	31.99	-.0396	1.794	.0042	379.9
600	1.00	1545	-.0232	1458.8	22.92	-.000	1.328	.351	42.73	-.0396	1.825	.0037	386.4
800	.75	1439	-.0235	1421.6	22.92	-.000	1.333	.347	52.48	-.0395	1.844	.0034	390.6
1000	.60	1361	-.0238	1394.6	22.92	-.000	1.337	.344	61.55	-.0394	1.858	.0031	393.6
1500	.40	1227	-.0240	1349.1	22.93	-.001	1.344	.339	82.25	-.0395	1.882	.0027	398.6
r = 1.6; o/f = 3.589; percent fuel = 21.79													
10	60.00	3391	0.0183	2461.1	22.16	-.142	1.164	0.900	2.36	-.0126	1.274	0.0105	267.3
15	40.00	3215	.0124	2341.4	22.31	-.111	1.181	.755	3.11	-.0158	1.364	.0097	286.1
20	30.00	3085	.0087	2260.8	22.40	-.088	1.197	.666	3.81	-.0188	1.421	.0092	298.1
30	20.00	2891	.0015	2153.6	22.51	-.057	1.221	.558	5.07	-.0238	1.494	.0083	313.4
40	15.00	2746	-.0045	2082.1	22.56	-.039	1.238	.499	6.21	-.0269	1.541	.0076	323.1
60	10.00	2538	-.0105	1987.8	22.61	-.021	1.261	.445	8.27	-.0309	1.600	.0068	335.6
80	7.50	2390	-.0133	1925.6	22.64	-.013	1.275	.419	10.13	-.0329	1.638	.0061	343.6
100	6.00	2277	-.0156	1879.9	22.65	-.009	1.284	.403	11.86	-.0338	1.665	.0057	349.3
150	4.00	2080	-.0177	1808.5	22.66	-.004	1.297	.386	15.81	-.0351	1.711	.0050	358.8
200	3.00	1946	-.0183	1751.7	22.66	-.002	1.304	.377	19.40	-.0355	1.740	.0045	364.9
300	2.00	1769	-.0191	1685.7	22.67	-.001	1.313	.368	25.89	-.0356	1.777	.0039	372.7
400	1.50	1651	-.0194	1642.6	22.67	-.000	1.319	.363	31.79	-.0358	1.801	.0036	377.7
600	1.00	1496	-.0198	1586.7	22.67	-.000	1.326	.357	42.49	-.0356	1.831	.0031	384.1
800	.75	1393	-.0201	1550.3	22.67	-.000	1.330	.353	52.20	-.0356	1.851	.0029	388.2
1000	.60	1318	-.0202	1523.8	22.67	-.000	1.336	.349	61.25	-.0357	1.865	.0027	391.1
1500	.40	1189	-.0203	1479.3	22.67	-.001	1.341	.347	81.89	-.0352	1.888	.0023	396.1
r = 2.5; o/f = 2.297; percent fuel = 30.33													
10	60.00	2798	0.0068	3393.8	21.15	-.057	1.210	0.617	2.27	-.0107	1.267	0.0065	252.9
15	40.00	2612	.0025	3290.9	21.22	-.039	1.221	.567	2.96	-.0134	1.353	.0058	270.0
20	30.00	2482	-.0005	3222.3	21.26	-.028	1.229	.535	3.60	-.0154	1.408	.0053	280.8
30	20.00	2302	-.0042	3131.8	21.29	-.016	1.241	.499	4.77	-.0173	1.476	.0046	294.5
40	15.00	2176	-.0060	3071.7	21.31	-.010	1.249	.479	5.84	-.0185	1.520	.0042	303.3
60	10.00	2006	-.0079	2992.6	21.32	-.005	1.259	.457	7.78	-.0195	1.576	.0037	314.4
80	7.50	1890	-.0089	2940.4	21.32	-.003	1.265	.446	9.55	-.0196	1.612	.0033	321.6
100	6.00	1803	-.0094	2902.0	21.32	-.002	1.270	.439	11.21	-.0198	1.637	.0031	326.7
150	4.00	1653	-.0097	2836.8	21.33	-.001	1.277	.430	15.02	-.0199	1.680	.0027	335.3
200	3.00	1552	-.0097	2793.9	21.33	-.001	1.280	.426	18.51	-.0197	1.708	.0024	340.8
300	2.00	1419	-.0100	2737.8	21.33	-.001	1.286	.418	24.86	-.0195	1.744	.0021	347.9
400	1.50	1330	-.0099	2700.9	21.33	-.001	1.291	.414	30.67	-.0196	1.767	.0020	352.5
600	1.00	1213	-.0096	2652.9	21.33	-.002	1.296	.409	41.27	-.0192	1.796	.0017	358.4
800	.75	1136	-.0088	2621.4	21.33	-.004	1.296	.410	50.96	-.0184	1.815	.0016	362.2
1000	.60	1079	-.0079	2598.4	21.34	-.009	1.293	.415	60.04	-.0174	1.829	.0015	364.9
1500	.40	988	-.0053	2559.5	21.37	-.028	1.272	.455	81.26	-.0131	1.852	.0014	369.5

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TABLE V. - Continued. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO 1500 FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLOURINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Equilibrium composition during isentropic expansion]

(b) Combustion-chamber pressure, 300 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(^{\circ}K)}$	Area ratio, ϵ	Area-ratio exponent, n_ϵ, $\left(\frac{\partial \ln \epsilon}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Thrust coefficient, C_F	Specific-impulse exponent, n_I, $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.00; o/f = 5.743; percent fuel = 14.83													
10	30.00	2893	0.0174	1912.1	23.35	-.141	1.183	0.762	2.30	-.0097	1.271	0.0102	243.8
15	20.00	2733	.0096	1815.4	23.52	-.106	1.197	.646	3.03	-.0142	1.358	.0095	259.9
20	15.00	2616	.0083	1750.5	23.62	-.094	1.208	.603	3.70	-.0159	1.414	.0090	270.6
30	10.00	2468	.0301	1664.3	23.81	-.211	1.174	.975	4.94	-.0030	1.485	.0086	284.1
40	7.50	2390	.0365	1606.2	24.00	-.322	1.149	1.465	6.14	.0036	1.530	.0086	292.9
60	5.00	2305	.0401	1528.0	24.33	-.409	1.132	2.108	8.44	.0057	1.590	.0089	304.3
80	3.75	2254	.0416	1474.7	24.57	-.454	1.125	2.580	10.63	.0062	1.629	.0091	311.8
100	3.00	2217	.0418	1434.5	24.77	-.480	1.120	2.920	12.74	.0058	1.658	.0093	317.4
150	2.00	2155	.0414	1363.9	25.12	-.512	1.115	3.354	17.79	.0052	1.708	.0095	326.9
200	1.50	2114	.0408	1315.6	25.37	-.526	1.112	3.565	22.59	.0045	1.741	.0096	333.3
300	1.00	2059	.0396	1249.8	25.72	-.536	1.108	3.773	31.74	.0030	1.786	.0097	341.7
400	.75	2022	.0391	1204.6	25.97	-.537	1.106	3.866	40.49	.0019	1.816	.0098	347.4
600	.50	1972	.0379	1143.1	26.32	-.540	1.103	3.955	57.20	.0005	1.855	.0098	355.1
800	.37	1938	.0370	1100.8	26.57	-.542	1.101	3.992	73.20	-.0005	1.882	.0098	360.2
1000	.30	1913	.0363	1068.8	26.76	-.543	1.100	4.003	88.70	-.0012	1.902	.0098	364.1
1500	.20	1868	.0351	1012.3	27.11	-.542	1.098	3.983	126.0	-.0024	1.937	.0098	370.7
r = 1.25; o/f = 4.595; percent fuel = 17.87													
10	30.00	3192	0.0179	2126.8	22.75	-.142	1.187	0.772	2.31	-.0119	1.271	0.0110	258.4
15	20.00	3012	.0112	2017.3	22.92	-.108	1.200	.663	3.03	-.0163	1.358	.0102	276.2
20	15.00	2878	.0047	1944.0	23.01	-.075	1.219	.571	3.70	-.0212	1.414	.0095	287.5
30	10.00	2673	-.0081	1847.0	23.10	-.027	1.262	.440	4.89	-.0306	1.484	.0084	301.8
40	7.50	2517	-.0076	1782.8	23.13	-.039	1.261	.448	5.95	-.0274	1.529	.0076	310.9
60	5.00	2342	.0268	1698.6	23.26	-.144	1.199	.783	7.97	-.0139	1.586	.0070	322.5
80	3.75	2267	.0362	1642.2	23.44	-.252	1.158	1.267	9.97	-.0037	1.623	.0071	330.0
100	3.00	2223	.0368	1599.9	23.61	-.334	1.139	1.694	11.93	.0020	1.650	.0073	335.6
150	2.00	2149	.0367	1525.8	23.92	-.418	1.125	2.225	16.60	.0042	1.697	.0075	345.0
200	1.50	2101	.0360	1475.3	24.15	-.432	1.120	2.385	21.06	.0032	1.728	.0077	351.3
300	1.00	2038	.0351	1406.7	24.47	-.430	1.118	2.394	29.54	.0015	1.769	.0078	359.7
400	.75	1995	.0338	1359.8	24.69	-.424	1.116	2.364	37.62	-.0000	1.797	.0079	365.4
600	.50	1937	.0313	1296.0	25.00	-.403	1.113	2.254	53.02	-.0029	1.834	.0080	372.9
800	.37	1897	.0290	1252.3	25.21	-.387	1.112	2.123	67.72	-.0047	1.859	.0080	377.9
1000	.30	1866	.0276	1219.3	25.37	-.371	1.113	1.996	81.91	-.0061	1.877	.0080	381.7
1500	.20	1809	.0243	1161.3	25.66	-.341	1.117	1.721	115.8	-.0086	1.909	.0079	388.3
r = 1.40; o/f = 4.102; percent fuel = 19.60													
10	30.00	3343	0.0196	2258.5	22.40	-.169	1.172	0.894	2.34	-.0121	1.273	0.0120	264.9
15	20.00	3168	.0132	2141.9	22.58	-.123	1.188	.740	3.08	-.0171	1.361	.0111	283.4
20	15.00	3035	.0060	2063.5	22.68	-.087	1.207	.622	3.77	-.0221	1.418	.0104	295.2
30	10.00	2828	-.0064	1959.6	22.78	-.036	1.249	.475	4.99	-.0315	1.490	.0093	310.1
40	7.50	2667	-.0144	1890.6	22.81	-.014	1.279	.412	6.08	-.0367	1.536	.0084	319.7
60	5.00	2435	-.0185	1800.6	22.83	-.004	1.303	.378	8.02	-.0390	1.593	.0071	331.7
80	3.75	2295	.0126	1741.5	22.87	-.083	1.247	.555	9.83	-.0204	1.630	.0066	339.3
100	3.00	2217	.0216	1697.9	22.96	-.177	1.180	.875	11.63	-.0085	1.657	.0064	344.9
150	2.00	2116	.0265	1622.3	23.20	-.256	1.148	1.242	16.04	-.0038	1.702	.0065	354.3
200	1.50	2056	.0261	1571.1	23.38	-.267	1.147	1.258	20.25	-.0039	1.732	.0065	360.5
300	1.00	1973	.0223	1502.1	23.64	-.242	1.147	1.167	28.21	-.0076	1.772	.0066	368.8
400	.75	1914	.0176	1455.2	23.80	-.203	1.153	1.018	35.69	-.0117	1.798	.0065	374.2
600	.50	1823	.0071	1392.2	24.00	-.136	1.176	.759	49.61	-.0202	1.833	.0064	381.5
800	.37	1749	.0008	1349.8	24.11	-.085	1.209	.596	62.39	-.0291	1.856	.0062	386.3
1000	.30	1684	-.0080	1318.2	24.17	-.049	1.239	.492	74.23	-.0375	1.873	.0059	389.9
1500	.20	1551	-.0334	1264.3	24.21	-.009	1.285	.373	100.8	-.0496	1.902	.0053	395.8
r = 1.50; o/f = 3.829; percent fuel = 20.71													
10	30.00	3376	0.0215	2354.5	22.15	-.184	1.165	0.977	2.35	-.0113	1.273	0.0122	267.2
15	20.00	3210	.0160	2235.2	22.33	-.150	1.173	.850	3.11	-.0151	1.362	.0114	286.0
20	15.00	3090	.0112	2154.8	22.45	-.122	1.182	.758	3.81	-.0183	1.420	.0108	297.9
30	10.00	2913	.0034	2047.3	22.59	-.081	1.202	.629	5.09	-.0241	1.492	.0099	313.8
40	7.50	2779	-.0030	1975.4	22.66	-.054	1.223	.543	6.25	-.0288	1.539	.0092	323.1
60	5.00	2576	-.0105	1880.3	22.72	-.029	1.255	.460	8.35	-.0340	1.599	.0081	335.6
80	3.75	2433	-.0081	1817.4	22.76	-.040	1.248	.480	10.25	-.0314	1.638	.0075	343.7
100	3.00	2333	-.0079	1771.0	22.80	-.042	1.245	.487	12.06	-.0306	1.665	.0070	349.5
150	2.00	2160	-.0114	1691.7	22.87	-.031	1.258	.455	16.24	-.0335	1.712	.0064	359.3
200	1.50	2035	-.0171	1639.3	22.90	-.015	1.280	.411	20.02	-.0379	1.742	.0059	365.5
300	1.00	1857	-.0230	1570.9	22.92	-.004	1.305	.373	26.80	-.0415	1.780	.0052	373.6
400	.75	1734	-.0247	1526.1	22.92	-.001	1.317	.361	32.91	-.0425	1.805	.0047	378.8
600	.50	1572	-.0254	1468.1	22.92	-.000	1.327	.352	43.96	-.0427	1.836	.0041	385.4
800	.37	1464	-.0258	1430.3	22.92	-.000	1.332	.349	54.00	-.0427	1.856	.0038	389.6
1000	.30	1384	-.0260	1402.7	22.92	-.000	1.336	.344	63.33	-.0427	1.871	.0035	392.7
1500	.20	1249	-.0263	1356.5	22.92	-.000	1.344	.339	84.62	-.0427	1.895	.0031	397.8
r = 1.60; o/f = 3.589; percent fuel = 21.79													
10	30.00	3346	0.0208	2473.4	22.05	-.170	1.156	1.013	2.38	-.0114	1.276	0.0112	265.3
15	20.00	3185	.0155	2354.5	22.22	-.138	1.170	.851	3.15	-.0145	1.366	.0105	284.1
20	15.00	3065	.0121	2274.3	22.32	-.111	1.184	.748	3.86	-.0175	1.424	.0099	296.1
30	10.00	2887	.0047	2167.1	22.45	-.076	1.206	.619	5.15	-.0226	1.498	.0091	311.5
40	7.50	2752	-.0017	2095.4	22.52	-.055	1.223	.546	6.33	-.0262	1.545	.0085	321.3
60	5.00	2554	-.0085	2000.6	22.59	-.032	1.249	.474	8.45	-.0310	1.606	.0076	333.9
80	3.75	2412	-.0127	1937.8	22.62	-.020	1.265	.438	10.37	-.0336	1.648	.0069	342.0
100	3.00	2301	-.0157	1891.6	22.64	-.013	1.276	.417	12.15	-.0354	1.673	.0064	347.8
150	2.00	2106	-.0190	1813.3	22.66	-.006	1.292	.393	16.21	-.0374	1.719	.0056	357.5
200	1.50	1972	-.0199	1761.8	22.66	-.003	1.301	.382	19.89	-.0381	1.749	.0051	363.7
300	1.00	1794	-.0215	1694.9	22.67	-.001	1.311	.370	26.56	-.0385	1.787	.0045	371.6
400	.75	1675	-.0218	1651.2	22.67	-.000	1.317	.364	32.61	-.0387	1.811	.0041	376.7
600	.50	1518	-.0220	1594.5	22.67	-.000	1.325	.357	43.58	-.0385	1.843	.0035	383.2
800	.37	1414	-.0223	1557.6	22.67	-.000	1.330	.353	53.55	-.0384	1.863	.0032	387.4
1000	.30	1337	-.0226	1530.7	22.67	-.000	1.335	.349	62.83	-.0385	1.877	.0030	390.4
1500	.20	1207	-.0228	1485.5	22.67	-.001	1.341	.345	83.99	-.0384	1.901	.0027	395.4

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TABLE V. - Concluded. THEORETICAL ROCKET PERFORMANCE AT ASSIGNED PRESSURE RATIOS FROM 10 TO 1500 FOR JP-4 FUEL AND OXIDANT CONTAINING 70.37 PERCENT FLOURINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Equilibrium composition during isentropic expansion]

(b) Concluded. Combustion-chamber pressure, 300 pounds per square inch absolute

Pressure ratio, P_c/P	Pressure, P, lb/sq in. abs	Temperature, T, °K	Temperature exponent, n_T, $\left(\frac{\partial \ln T}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Enthalpy, h, cal/g	Molecular weight, M	Partial derivative, ξ, $\left(\frac{\partial \ln M}{\partial \ln T}\right)_s$	Isentropic exponent, γ, $\left(\frac{\partial \ln P}{\partial \ln \rho}\right)_s$	Specific heat, c_p, $\frac{cal}{(g)(°K)}$	Area ratio, ε	Area-ratio exponent, n_ϵ, $\left(\frac{\partial \ln \epsilon}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Thrust coefficient, C_F	Specific-impulse exponent, n_I, $\left(\frac{\partial \ln I}{\partial \ln P_c}\right)_{\frac{P_c}{P}}$	Specific impulse, I, $\frac{lb\text{-}sec}{lb}$
r = 1.75; o/f = 3.282; percent fuel = 23.35													
10	30.00	3854	0.0187	2638.5	21.85	-.139	1.177	0.843	2.36	-.0094	1.272	0.0097	263.6
15	20.00	3076	.0131	2522.2	22.01	-.108	1.192	.724	3.10	-.0133	1.362	.0091	282.2
20	15.00	2946	.0090	2444.2	22.10	-.088	1.203	.655	3.78	-.0161	1.419	.0086	294.0
30	10.00	2758	.0028	2340.4	22.21	-.063	1.220	.574	5.03	-.0200	1.491	.0078	308.9
40	7.50	2623	-.0015	2271.3	22.27	-.047	1.232	.527	6.17	-.0230	1.537	.0073	318.5
60	5.00	2431	-.0071	2180.0	22.33	-.029	1.250	.475	8.84	-.0266	1.596	.0065	330.8
80	3.75	2296	-.0106	2119.5	22.36	-.020	1.268	.446	10.12	-.0288	1.634	.0060	338.6
100	3.00	2192	-.0129	2075.0	22.38	-.014	1.272	.428	11.87	-.0303	1.662	.0056	344.3
150	2.00	2008	-.0159	1999.5	22.40	-.005	1.287	.403	15.86	-.0323	1.707	.0049	353.7
200	1.50	1882	-.0176	1949.9	22.40	-.003	1.295	.391	19.48	-.0329	1.736	.0044	359.8
300	1.00	1714	-.0183	1885.3	22.41	-.001	1.305	.379	26.05	-.0334	1.773	.0039	367.5
400	.75	1602	-.0187	1843.0	22.41	-.001	1.311	.374	32.02	-.0333	1.797	.0035	372.5
600	.50	1453	-.0192	1788.1	22.41	-.000	1.318	.368	42.86	-.0334	1.828	.0031	378.8
800	.37	1355	-.0195	1758.3	22.41	-.000	1.324	.362	52.72	-.0334	1.848	.0028	382.9
1000	.30	1283	-.0196	1726.2	22.41	-.000	1.328	.359	61.90	-.0334	1.862	.0026	385.9
1500	.20	1160	-.0194	1682.3	22.41	-.001	1.334	.356	82.87	-.0332	1.886	.0023	390.8
r = 2.00; o/f = 2.872; percent fuel = 25.83													
10	30.00	3075	0.0154	2905.1	21.57	-.111	1.192	0.744	2.31	-.0103	1.269	0.0090	260.1
15	20.00	2894	.0101	2793.9	21.70	-.088	1.203	.668	3.03	-.0137	1.357	.0084	278.1
20	15.00	2765	.0064	2719.5	21.78	-.072	1.211	.620	3.70	-.0160	1.412	.0078	289.5
30	10.00	2582	.0009	2620.8	21.87	-.050	1.225	.556	4.92	-.0199	1.483	.0071	304.0
40	7.50	2453	-.0038	2555.1	21.92	-.036	1.236	.517	6.03	-.0226	1.528	.0066	313.2
60	5.00	2270	-.0081	2468.4	21.97	-.021	1.251	.472	8.05	-.0256	1.586	.0058	325.1
80	3.75	2142	-.0109	2411.0	21.99	-.013	1.263	.448	9.89	-.0273	1.623	.0053	332.6
100	3.00	2045	-.0109	2368.8	22.00	-.008	1.271	.432	11.60	-.0284	1.650	.0050	338.1
150	2.00	1874	-.0146	2297.1	22.01	-.003	1.283	.412	15.51	-.0295	1.694	.0043	347.2
200	1.50	1758	-.0154	2249.9	22.01	-.002	1.290	.403	19.08	-.0297	1.723	.0039	353.1
300	1.00	1603	-.0162	2188.4	22.01	-.001	1.298	.393	25.56	-.0298	1.759	.0034	360.6
400	.75	1500	-.0166	2148.2	22.01	-.000	1.303	.388	31.46	-.0299	1.783	.0031	365.4
600	.50	1364	-.0168	2095.8	22.01	-.000	1.311	.381	42.19	-.0299	1.813	.0028	371.6
800	.37	1273	-.0169	2061.6	22.01	-.000	1.316	.376	51.97	-.0299	1.833	.0025	375.6
1000	.30	1207	-.0169	2036.6	22.01	-.001	1.319	.374	61.10	-.0297	1.847	.0024	378.5
1500	.20	1092	-.0160	1994.5	22.01	-.001	1.316	.378	81.91	-.0290	1.870	.0021	383.3
r = 2.50; o/f = 2.297; percent fuel = 30.33													
10	30.00	2788	0.0094	3400.8	21.09	-.073	1.201	0.668	2.28	-.0110	1.268	0.0074	251.7
15	20.00	2607	.0046	3298.1	21.18	-.052	1.212	.606	2.99	-.0142	1.355	.0067	268.9
20	15.00	2462	.0010	3229.5	21.23	-.039	1.221	.567	3.64	-.0164	1.410	.0062	279.7
30	10.00	2308	-.0035	3138.7	21.27	-.024	1.234	.520	4.83	-.0189	1.479	.0055	293.5
40	7.50	2186	-.0059	3078.4	21.29	-.015	1.243	.494	5.92	-.0204	1.524	.0050	302.3
60	5.00	2017	-.0086	2998.9	21.31	-.008	1.256	.465	7.89	-.0218	1.580	.0043	313.6
80	3.75	1902	-.0102	2946.4	21.32	-.004	1.263	.451	9.69	-.0226	1.617	.0039	320.8
100	3.00	1815	-.0109	2907.7	21.32	-.003	1.268	.443	11.38	-.0226	1.643	.0036	326.0
150	2.00	1665	-.0114	2842.0	21.33	-.001	1.275	.432	15.25	-.0230	1.686	.0032	334.6
200	1.50	1564	-.0115	2798.8	21.33	-.000	1.280	.427	18.78	-.0230	1.715	.0029	340.2
300	1.00	1430	-.0118	2742.3	21.33	-.000	1.287	.418	25.23	-.0229	1.751	.0025	347.3
400	.75	1340	-.0119	2705.1	21.33	-.000	1.292	.412	31.12	-.0228	1.774	.0023	352.0
600	.50	1223	-.0118	2656.8	21.33	-.001	1.297	.407	41.87	-.0225	1.804	.0020	357.9
800	.37	1144	-.0117	2625.0	21.33	-.002	1.300	.408	51.68	-.0221	1.823	.0019	361.7
1000	.30	1086	-.0111	2601.9	21.33	-.004	1.301	.410	60.84	-.0217	1.837	.0018	364.5
1500	.20	990	-.0079	2563.7	21.34	-.013	1.291	.423	82.08	-.0190	1.861	.0016	369.2
r = 3.00; o/f = 1.914; percent fuel = 34.31													
10	30.00	2536	0.0041	3841.9	20.65	-.039	1.211	0.606	2.27	-.0106	1.268	0.0055	243.6
15	20.00	2365	.0000	3746.4	20.70	-.025	1.223	.560	2.97	-.0128	1.354	.0048	260.1
20	15.00	2246	-.0031	3682.7	20.72	-.017	1.229	.535	3.61	-.0140	1.408	.0044	270.6
30	10.00	2081	-.0045	3598.6	20.74	-.009	1.240	.505	4.77	-.0154	1.477	.0038	283.7
40	7.50	1968	-.0058	3542.8	20.75	-.005	1.247	.490	5.84	-.0161	1.521	.0034	292.2
60	5.00	1815	-.0070	3469.4	20.75	-.002	1.254	.474	7.79	-.0162	1.577	.0029	302.9
80	3.75	1711	-.0074	3420.9	20.75	-.001	1.259	.466	9.58	-.0164	1.613	.0027	309.8
100	3.00	1634	-.0074	3385.1	20.75	-.001	1.263	.461	11.25	-.0163	1.638	.0025	314.8
150	2.00	1501	-.0075	3334.3	20.75	-.001	1.268	.453	15.11	-.0160	1.682	.0021	323.1
200	1.50	1412	-.0075	3284.2	20.76	-.001	1.272	.448	18.64	-.0161	1.709	.0020	328.4
300	1.00	1293	-.0075	3231.8	20.76	-.001	1.280	.439	25.09	-.0160	1.745	.0017	335.3
400	.75	1215	-.0074	3197.2	20.76	-.001	1.282	.437	31.00	-.0158	1.768	.0016	339.8
600	.50	1110	-.0064	3152.1	20.76	-.004	1.283	.440	41.78	-.0151	1.798	.0014	345.5
800	.37	1041	-.0042	3122.5	20.77	-.010	1.281	.450	51.69	-.0137	1.818	.0013	349.2
1000	.30	993	-.0026	3100.8	20.78	-.020	1.274	.463	61.09	-.0113	1.832	.0012	351.9
1500	.20	918	.0055	3063.8	20.84	-.061	1.248	.544	83.39	-.0039	1.855	.0012	356.4
r = 4.00; o/f = 1.436; percent fuel = 41.05													
10	30.00	2130	-.0004	4589.7	19.84	-.008	1.223	0.560	2.24	-.0060	1.266	0.0023	229.0
15	20.00	1977	-.0015	4506.3	19.85	-.004	1.230	.541	2.92	-.0064	1.351	.0019	244.3
20	15.00	1873	-.0021	4450.9	19.85	-.002	1.234	.531	3.55	-.0066	1.404	.0017	254.0
30	10.00	1734	-.0025	4377.7	19.85	-.001	1.239	.519	4.70	-.0065	1.472	.0014	266.3
40	7.50	1639	-.0025	4329.2	19.85	-.001	1.243	.513	5.76	-.0065	1.515	.0013	274.1
60	5.00	1514	-.0024	4265.2	19.85	-.001	1.248	.506	7.70	-.0062	1.570	.0011	284.1
80	3.75	1429	-.0024	4222.8	19.86	-.001	1.252	.499	9.48	-.0064	1.606	.0010	290.5
100	3.00	1366	-.0024	4191.6	19.86	-.001	1.254	.494	11.15	-.0061	1.632	.0009	295.1
150	2.00	1258	-.0020	4138.4	19.86	-.003	1.260	.489	15.00	-.0059	1.674	.0008	302.9
200	1.50	1186	-.0014	4103.2	19.86	-.005	1.260	.491	18.54	-.0054	1.702	.0008	307.9
300	1.00	1091	.0007	4057.1	19.87	-.013	1.258	.503	25.04	-.0036	1.738	.0007	314.3
400	.75	1030	.0034	4026.6	19.89	-.025	1.253	.523	31.07	-.0015	1.761	.0007	318.5
600	.50	955	.0100	3986.5	19.95	-.059	1.238	.591	42.39	.0041	1.791	.0007	323.9
800	.37	912	.0168	3959.8	20.03	-.100	1.213	.710	53.16	.0090	1.811	.0008	327.5
1000	.30	884	.0213	3940.0	20.10	-.130	1.166	.970	63.67	.0094	1.835	.0009	330.1
1500	.20	847	.0260	3905.5	20.29	-.164	1.155	1.155	89.45	.0129	1.850	.0012	334.6

TABLE VI. - THEORETICAL PERFORMANCE FOR EXPANSION TO 1 ATMOSPHERE FOR JP-4 FUEL WITH OXIDANT CONTAINING 70.37 PERCENT FLUORINE AND 29.63 PERCENT OXYGEN BY WEIGHT

[Equilibrium composition during isentropic expansion.]

Equivalence ratio, r, $\frac{4(C)+(H)}{2(O)+(F)}$	Percent fuel by weight	Oxidant-to-fuel weight ratio, o/f	Combustion temperature, T_c, $^{\circ}K$	Exit temperature, T_e, $^{\circ}K$	Characteristic velocity, c^*, ft/sec	Coefficient of thrust, C_F	Area ratio, ϵ	Specific impulse, I, lb-sec/lb
Combustion-chamber pressure, 600 lb/sq in. abs								
1.00	14.83	5.743	4007	2452	6203	1.532	6.26	295.3
1.40	19.60	4.102	4464	2627	6757	1.533	6.01	322.0
1.50	20.71	3.829	4479	2758	6814	1.538	6.22	325.7
1.60	21.79	3.589	4396	2736	6749	1.544	6.30	323.9
2.50	30.33	2.297	3898	2168	6420	1.523	5.92	303.9
Combustion-chamber pressure, 300 lb/sq in. abs								
1.00	14.83	5.743	3910	2608	6157	1.418	3.75	271.3
1.25	17.87	4.595	4238	2868	6543	1.418	3.75	288.3
1.40	19.60	4.102	4332	3026	6697	1.422	3.82	296.0
1.50	20.71	3.829	4346	3081	6753	1.423	3.86	298.8
1.60	21.79	3.589	4267	3056	6691	1.428	3.91	296.9
1.75	23.35	3.282	4163	2936	6667	1.423	3.84	294.8
2.00	25.83	2.872	4067	2755	6594	1.416	3.75	290.3
2.50	30.33	2.297	3813	2473	6384	1.414	3.69	280.5
3.00	34.31	1.914	3552	2237	6181	1.412	3.66	271.3
4.00	41.05	1.436	3095	1866	5819	1.408	3.60	254.7

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CM-5

TABLE VII. - EQUILIBRIUM COMPOSITION OF PRODUCTS OF REACTION AT ASSIGNED TEMPERATURES FOR JP-4 FUEL AND OXYDANT CONTAINING 70.37 PERCENT FLOURINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Isentropic expansion or compression from combustion conditions.]

(a) Combustion-chamber pressure, 600 pounds per square inch absolute

Mole fraction[a] at temperature T

r = 1; o/f = 5.743; percent fuel = 14.83

T, °K	4400	[b]4007	4000	3600	3200	2800	2400	2000	1600	900	
CF_4	--	--	--	--	0.00001	0.00018	0.00836	0.03269	0.06574	0.08743	
CO	0.20805	0.20066	0.20047	0.18636	.16467	.14054	.11887	.08143	.03218	--	
CO_2	.02381	.03547	.03574	.05447	.08103	.10945	.13275	.17058	.22012	.25246	
F	.25416	.25010	.25007	.25013	.25325	.25668	.23400	.16218	.06429	--	
F_2	.00007	.00006	.00006	.00005	.00004	.00004	.00003	.00001	--	--	
H	.00801	.00339	.00333	.00108	.00021	.00002	--	--	--	--	
H_2	.00058	.00018	.00018	.00004	--	--	--	--	--	--	
HF	.43456	.45135	.45163	.46531	.47665	.48580	.50491	.55292	.61765	.66011	
H_2O	.00058	.00027	.00027	.00009	.00002	--	--	--	--	--	
O	.04677	.03517	.03494	.02155	.00969	.00233	.00030	.00004	--	--	
O_2	.01800	.02039	.02042	.01984	.01414	.00491	.00077	.00015	.00002	--	
OH	.00542	.00294	.00290	.00115	.00029	.00003	--	--	--	--	

r = 1.40; o/f = 4.102; percent fuel = 19.60

T, °K	4800	[b]4464	4400	4000	3600	3200	2800	2400	2000	1600	1200
C(GAS)	0.00001	--	--	--	--	--	--	--	--	--	--
CF	.00001	--	--	--	--	--	--	--	--	--	--
CF_4	--	--	--	--	--	--	--	0.00055	0.01068	0.01521	0.01530
CO	.28924	0.29436	0.29530	0.30053	0.30343	0.30274	0.30108	.30030	.29221	.28860	.28853
CO_2	.00228	.00312	.00334	.00542	.00937	.01523	.01894	.02014	.03108	.03597	.03607
F	.14374	.12346	.11956	.09565	.07488	.06179	.05801	.05559	.01744	.00034	--
F_2	.00001	.00001	.00001	--	--	--	--	--	--	--	--
H	.06281	.04781	.04492	.02737	.01241	.00313	.00030	.00001	--	--	--
H_2	.01175	.00871	.00813	.00467	.00187	.00035	.00002	--	--	--	--
HF	.47487	.50784	.51421	.55362	.58894	.61299	.62112	.62338	.64860	.65988	.66011
H_2O	.00081	.00081	.00081	.00072	.00047	.00013	.00001	--	--	--	--
O	.01084	.01043	.01031	.00907	.00652	.00279	.00043	.00002	--	--	--
O_2	.00029	.00037	.00039	.00054	.00063	.00042	.00007	--	--	--	--
OH	.00336	.00308	.00301	.00241	.00147	.00044	.00003	--	--	--	--

r = 1.50; o/f = 3.829; percent fuel = 20.71

T, °K	4800	[b]4479	4400	4000	3600	3200	2800	2400	2000	1600	1200
C(GAS)	0.00121	0.00099	0.00093	0.00060	0.00026	0.00006	--	--	--	--	--
GRAPHITE	--	--	--	--	--	--	--	--	--	--	0.00005
CF	.00128	.00117	.00114	.00090	.00055	.00023	0.00005	--	--	--	--
CF_2	.00005	.00005	.00005	.00004	.00003	.00002	.00001	0.00001	--	--	--
CF_3	.00001	.00001	.00001	.00001	--	--	.00001	.00002	--	--	--
CF_4	--	--	--	--	--	.00001	.00004	.00139	0.00311	0.00328	.00328
C_2F_2	.00028	.00042	.00046	.00077	.00115	.00145	.00156	.00092	.00008	--	--
CO	.30145	.30754	.30907	.31680	.32406	.32985	.33313	.33499	.33647	.33661	.33651
CO_2	.00002	.00001	.00001	--	--	--	--	--	--	--	.00005
F	.12128	.10077	.09556	.06922	.04433	.02421	.01243	.00577	.00052	.00001	--
F_2	.00001	.00001	--	--	--	--	--	--	--	--	--
H	.07694	.06245	.05877	.04020	.02282	.00920	.00179	.00013	.00001	--	--
H_2	.01725	.01423	.01346	.00962	.00591	.00268	.00052	.00003	.00001	--	--
HF	.48004	.51231	.52049	.56184	.60085	.63229	.65044	.65673	.65979	.66010	.66011
H_2O	.00001	--	--	--	--	--	--	--	--	--	--
O	.00011	.00003	.00002	--	--	--	--	--	--	--	--
OH	.00004	.00001	.00001	--	--	--	--	--	--	--	--

r = 1.60; o/f = 3.589; percent fuel = 21.79

T, °K	4400	[b]4396	4000	3600	3200	2800	2400	2000	1600	1200	900
C(GAS)	0.00411	0.00409	0.00255	0.00078	0.00010	0.00001	--	--	--	--	--
GRAPHITE	--	--	--	.01261	.02198	.02433	0.02463	0.02467	0.02468	0.02473	0.02915
CF	.00420	.00419	.00285	.00106	.00019	.00001	--	--	--	--	--
CF_2	.00015	.00015	.00010	.00004	.00001	--	--	--	--	--	--
CF_3	.00002	.00002	.00001	--	--	--	--	--	--	--	--
C_2F_2	.00746	.00748	.00923	.00484	.00105	.00010	--	--	--	--	--
CO	.30364	.30371	.31108	.31387	.31621	.31857	.31977	.32014	.32020	.32010	.31135
CO_2	--	--	--	--	--	--	--	--	--	.00005	.00439
F	.06782	.06758	.04358	.02554	.01084	.00246	.00026	.00001	--	--	--
H	.07002	.06986	.05343	.03458	.01855	.00823	.00253	.00040	.00002	--	--
H_2	.02258	.02255	.02013	.01530	.01180	.01184	.01354	.01449	.01468	.01469	.01460
HF	.51997	.52035	.55703	.59136	.61927	.63446	.63926	.64028	.64042	.64042	.64042
H_2O	--	--	--	--	--	--	--	--	--	--	.00009

r = 2.50; o/f = 2.297; percent fuel = 30.33

T, °K	4000	[b]3898	3600	3200	2800	2400	2000	1600	1200	900	
C(GAS)	0.00098	0.00069	0.00021	0.00002	--	--	--	--	--	--	
GRAPHITE	.14771	.14949	.15304	.15560	0.15706	0.15785	0.15813	0.15819	0.15831	0.16450	
CF	.00066	.00047	.00015	.00002	--	--	--	--	--	--	
CF_2	.00001	.00001	--	--	--	--	--	--	--	--	
C_2F_2	.00163	.00114	.00035	.00005	--	--	--	--	--	--	
CH_4	.00002	.00002	.00001	.00001	.00001	.00001	.00001	.00001	.00003	.00013	
CO	.22351	.22398	.22566	.22807	.23001	.23114	.23155	.23162	.23144	.22037	
CO_2	--	--	--	--	--	--	--	--	.00007	.00493	
F	.00790	.00660	.00352	.00116	.00025	.00003	--	--	--	--	
H	.06950	.06463	.04966	.02986	.01379	.00424	.00070	.00004	--	--	
H_2	.11289	.11438	.12044	.13033	.13909	.14447	.14649	.14685	.14679	.14520	
HF	.43518	.43859	.44695	.45486	.45977	.46826	.46312	.46327	.46330	.46340	
H_2O	--	--	--	--	--	--	--	.00001	.00007	.00147	

[a]Mole fractions were computed for all 19 substances considered in this report but are omitted if less than 5×10^{-6}.

[b]Combustion temperature.

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TABLE VII. - Continued. EQUILIBRIUM COMPOSITION OF PRODUCTS OF REACTION AT ASSIGNED TEMPERATURES FOR JP-4 OXYDANT CONTAINING 70.37 PERCENT FLOURINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Isentropic expansion or compression from combustion conditions]

(b) Combustion-chamber pressure, 300 pounds per square inch absolute

Mole fraction[a] at temperature T											
r = 1.00; o/f = 5.743; percent fuel = 14.83											
T, °K	4000	[b]3910	3600	3200	2800	2400	2000	1600	900		
CF_4	—	—	—	—	0.00002	0.00297	0.02543	0.05970	0.08743		
CO	0.20602	0.20406	0.19426	0.17363	.14676	.12710	.09216	.04112	—		
CO_2	.02758	.03063	.04429	.07021	.10220	.12443	.15981	.21113	.25246		
F	.25049	.24972	.24901	.25171	.25618	.24995	.18369	.08219	—		
F_2	.00003	.00003	.00003	.00002	.00002	.00002	—	—	—		
H	.00543	.00433	.00174	.00037	.00004	—	—	—	—		
H_2	.00028	.00021	.00006	.00001	—	—	—	—	—		
HF	.44348	.44748	.45969	.47271	.48344	.49427	.53873	.60584	.66010		
H_2O	.00032	.00027	.00011	.00002	—	—	—	—	—		
O	.04365	.04048	.02869	.01405	.00391	.00038	.00004	—	—		
O_2	.01915	.01977	.02061	.01685	.00737	.00087	.00013	.00001	—		
OH	.00355	.00302	.00151	.00042	.00005	—	—	—	—		
r = 1.25; o/f = 4.596; percent fuel = 17.87											
T, °K	4400	[b]4238	4000	3600	3200	2800	2400	2000	1600	900	
CF_4	—	—	—	—	—	—	0.00050	0.01646	0.03522	0.03694	
CO	0.26461	0.26594	0.26697	0.26481	0.25565	0.24415	.24003	.22326	.20376	.20197	
CO_2	.00717	.00862	.01166	.02041	.03541	.05090	.05614	.07591	.09888	.10098	
F	.17148	.16285	.15122	.13624	.12943	.12855	.12699	.07138	.00600	—	
F_2	.00001	.00001	.00001	—	—	—	—	—	—	—	
H	.03679	.02976	.02024	.00794	.00183	.00019	.00001	—	—	—	
H_2	.00428	.00328	.00202	.00060	.00009	—	—	—	—	—	
HF	.47453	.48970	.51102	.54167	.56237	.57273	.57615	.61298	.65615	.66011	
H_2O	.00102	.00093	.00075	.00038	.00009	.00001	—	—	—	—	
O	.03141	.03030	.02781	.02060	.01023	.00217	.00012	.00001	—	—	
O_2	.00286	.00328	.00398	.00500	.00420	.00122	.00007	—	—	—	
OH	.00590	.00533	.00432	.00234	.00070	.00007	—	—	—	—	
r = 1.40; o/f = 4.102; percent fuel = 19.60											
T, °K	4400	[b]4332	4000	3600	3200	2800	2400	2000	1600	1200	900
CF_4	—	—	—	—	—	—	0.00004	0.00801	0.01510	0.01530	0.01530
CO	0.29137	0.29255	0.29797	0.30277	0.30353	0.30142	.30073	.29434	.28869	.28853	.28853
CO_2	.00239	.00257	.00391	.00706	.01290	.01832	.01955	.02820	.03585	.03607	.03607
F	.13363	.12910	.10699	.08239	.06478	.05836	.05755	.02749	.00075	—	—
F_2	.00001	.00001	—	—	—	—	—	—	—	—	—
H	.05854	.05502	.03783	.01890	.00559	.00061	.00002	—	—	—	—
H_2	.00903	.00843	.00556	.00252	.00058	.00004	—	—	—	—	—
HF	.48978	.49719	.53365	.57511	.60674	.62018	.62206	.64196	.65961	.66011	.66011
H_2O	.00065	.00065	.00062	.00048	.00019	.00002	—	—	—	—	—
O	.01144	.01135	.01058	.00845	.00446	.00085	.00004	—	—	—	—
O_2	.00032	.00034	.00045	.00062	.00056	.00014	.00001	—	—	—	—
OH	.00284	.00279	.00243	.00169	.00066	.00007	—	—	—	—	—
r = 1.50; o/f = 3.829; percent fuel = 20.71											
T, °K	4400	[b]4346	4000	3600	3200	2800	2400	2000	1600	1200	900
C(GAS)	0.00122	0.00118	0.00088	0.00045	0.00018	0.00001	—	—	—	—	—
GRAPHITE	—	—	—	—	—	—	—	0.00004	—	0.00002	0.00214
CF	.00114	.00112	.00098	.00067	.00030	.00008	0.00001	—	—	—	—
CF_2	.00004	.00004	.00004	.00003	.00002	.00001	.00001	—	—	—	—
CF_3	—	—	—	—	—	—	.00001	—	—	—	—
CF_4	—	—	—	—	—	.00001	.00070	.00299	0.00328	.00328	.00328
C_2F_2	.00030	.00033	.00058	.00099	.00137	.00156	.00126	.00012	—	—	—
CO	.30395	.30508	.31253	.32096	.32811	.33256	.33439	.33635	.33661	.33657	.33234
CO_2	.00001	.00001	—	—	—	—	—	—	—	.00002	.00214
F	.11094	.10713	.08218	.05397	.02983	.01439	.00791	.00091	.00002	—	—
H	.07336	.07053	.05204	.03123	.01375	.00313	.00020	.00001	—	—	—
H_2	.01378	.01329	.01009	.00647	.00320	.00079	.00004	.00001	—	—	—
HF	.49522	.50124	.54068	.58522	.62329	.64746	.65548	.65957	.66009	.66011	.66011
O	.00003	.00002	—	—	—	—	—	—	—	—	—
OH	.00001	.00001	—	—	—	—	—	—	—	—	—
r = 1.60; o/f = 3.589; percent fuel = 21.79											
T, °K	4400	[b]4267	4000	3600	3200	2800	2400	2000	1600	1200	900
C(GAS)	0.00576	0.00513	0.00382	0.00133	0.00019	0.00001	—	—	—	—	—
GRAPHITE	—	—	—	.01149	.02159	.02425	0.02462	0.02467	0.02468	0.02470	0.02695
CF	.00470	.00429	.00338	.00139	.00026	.00002	—	—	—	—	—
CF_2	.00014	.00012	.00010	.00004	.00001	—	—	—	—	—	—
CF_3	.00001	.00001	.00001	—	—	—	—	—	—	—	—
C_2F_2	.00619	.00683	.00817	.00486	.00109	.00011	—	—	—	—	—
CO	.29842	.30119	.30678	.31118	.31462	.31791	.31958	.32011	.32020	.32016	.31571
CO_2										.00002	.00823
F	.08193	.07292	.05492	.03335	.01513	.00362	.00039	.00002	—	—	—
H	.08387	.07775	.06527	.04398	.02444	.01120	.00359	.00058	.00003	—	—
H_2	.02142	.02052	.01887	.01456	.01101	.01091	.01307	.01440	.01467	.01469	.01464
HF	.49758	.51123	.53869	.57780	.61164	.63197	.63876	.64021	.64041	.64048	.64042
H_2O	—	—	—	—	—	—	—	—	—	—	.00005
O	.00001	—	—	—	—	—	—	—	—	—	—

[a]Mole fractions were computed for all 19 substances considered in this report but are omitted if less than 5×10^{-6}.

[b]Combustion temperature.

TABLE VII. - Concluded. EQUILIBRIUM COMPOSITION OF PRODUCTS OF REACTION AT ASSIGNED TEMPERATURES FOR JP-4 OXIDANT CONTAINING 70.37 PERCENT FLOURINE AND 29.63 PERCENT OXYGEN BY WEIGHT.

[Isentropic expansion or compression from combustion conditions.]

(b) Concluded. Combustion-chamber pressure, 300 pounds per square inch absolute

Mole fraction[a] at temperature T											
r = 1.75; o/f = 3.282; percent fuel = 23.35											
T, °K	4400	[b]4163	4000	3600	3200	2800	2400	2000	1600	1200	900
C(GAS)	0.00991	0.00637	0.00421	0.00109	0.00015	0.00001	—	—	—	—	—
GRAPHITE	—	.01596	.02749	.04514	.05148	.05308	0.05344	0.05357	0.05359	0.05362	0.05605
CF	.00679	.00452	.00308	.00087	.00013	.00001	—	—	—	—	—
CF_2	.00017	.00011	.00007	.00008	—	—	—	—	—	—	—
CF_3	.00001	.00001	—	—	—	—					
C_2F_2	.01740	.01232	.00834	.00236	.00037	.00003	—	—	—	—	—
CO	.29017	.28988	.28945	.29116	.29488	.29821	.30017	.30089	.30102	.30097	.29626
CO_2	—	—	—	—	—	—	—	—	—	.00003	.00231
F	.05102	.04260	.03697	.02100	.00768	.00163	.00018	.00001	—	—	—
H	.09785	.08550	.07651	.05491	.03479	.01784	.00551	.00089	.00005	—	—
H_2	.03932	.03497	.03185	.02777	.02933	.03515	.04054	.04286	.04330	.04332	.04317
HF	.48737	.50775	.52808	.55568	.58119	.59472	.60016	.60177	.60204	.60205	.60206
H_2O	—	—	—	—	—	—	—	—	—	.00001	.00015
r = 2.00; o/f = 2.872; percent fuel = 25.83											
T, °K	4400	[b]4067	4000	3600	3200	2800	2400	2000	1600	1200	900
C(GAS)	0.00819	0.00372	0.00307	0.00073	0.00009	—	—	—	—	—	—
GRAPHITE	.05310	.07393	.07697	.08823	.09225	0.09377	0.09448	0.09474	0.09479	0.09483	0.09755
CF	.00494	.00229	.00189	.00047	.00007	—	—	—	—	—	—
CF_2	.00011	.00005	.00004	.00001	—	—	—	—	—	—	—
CF_3	.00001	—	—	—	—	—	—	—	—	—	—
C_2F_2	.01221	.00527	.00430	.00100	.00014	.00001	—	—	—	—	—
CH_4	—	—	—	—	—	—	—	—	—	—	.00001
CO	.26208	.26137	.26153	.26402	.26765	.27085	.27281	.27355	.27369	.27363	.26851
CO_2	—	—	—	—	—	—	—	—	—	.00003	.00243
F	.03396	.02474	.02268	.01128	.00380	.00088	.00010	—	—	—	—
H	.10493	.08877	.08536	.06395	.04100	.02005	.00636	.00104	.00006	—	—
H_2	.05986	.05477	.05433	.05602	.06384	.07364	.08071	.08356	.08409	.08410	.08375
HF	.46060	.48509	.48981	.51434	.53116	.54085	.54553	.54710	.54738	.54740	.54741
H_2O	—	—	—	—	—	—	—	—	—	.00001	.00034
r = 2.50; o/f = 2.297; percent fuel = 30.33											
T, °K	4000	[b]3813	3600	3200	2800	2400	2000	1600	1200	900	
C(GAS)	0.00161	0.00085	0.00036	0.00004	—	—	—	—	—	—	
GRAPHITE	.14539	.14886	.15164	.15477	0.15665	0.15771	0.15811	0.15819	0.15825	0.16160	
CF	.00086	.00046	.00020	.00003	—	—	—	—	—	—	
CF_2	.00001	.00001	—	—	—	—	—	—	—	—	
C_2F_2	.00170	.00087	.00037	.00005	—	—	—	—	—	—	
CH_4	.00001	.00001	.00001	—	—	—	—	—	.00001	.00007	
CO	.22139	.22246	.22394	.22690	.22940	.23094	.23152	.23163	.23154	.22554	
CO_2	—	—	—	—	—	—	—	—	.00004	.00267	
F	.01034	.00743	.00473	.00159	.00036	.00004	—	—	—	—	
H	.08588	.07575	.06338	.03988	.01895	.00600	.00100	.00006	—	—	
H_2	.10476	.10801	.11315	.12498	.13618	.14347	.14632	.14686	.14685	.14600	
HF	.42813	.43528	.44222	.45208	.45844	.46183	.46304	.46327	.46329	.46334	
H_2O	—	—	—	—	—	—	—	—	.00003	.00079	
r = 3.00; o/f = 1.914; percent fuel = 34.31											
T, °K	3600	[b]3552	3200	2800	2400	2000	1600	1200	900		
C(GAS)	0.00019	0.00016	0.00002	—	—	—	—	—	—		
GRAPHITE	.19815	.19856	.20105	0.20302	0.20417	0.20461	0.20469	0.20478	0.20891		
CF	.00011	.00009	.00001	—	—	—	—	—	—		
C_2F_2	.00020	.00016	.00003	—	—	—	—	—	—		
CH_4	.00002	.00002	.00002	.00001	.00001	.00001	.00001	.00004	.00018		
CO	.19506	.19533	.19731	.19916	.20027	.20070	.20077	.20065	.19356		
CO_2	—	—	—	—	—	—	—	.00004	.00298		
F	.00254	.00227	.00086	.00019	.00002	—	—	—	—		
H	.05544	.05280	.03391	.01604	.00507	.00085	.00005	—	—		
H_2	.16121	.16261	.17310	.18345	.18992	.19243	.19290	.19284	.19133		
HF	.38707	.38799	.39369	.39812	.40053	.40140	.40157	.40159	.40171		
H_2O	—	—	—	—	—	—	.00001	.00006	.00134		
r = 4.00; o/f = 1.436; percent fuel = 41.05											
T, °K	3200	[b]3095	2800	2400	2000	1600	1200	900			
C(GAS)	0.00001	—	—	—	—	—	—	—			
GRAPHITE	.26313	0.26566	0.26688	0.26789	0.26827	0.26835	0.26851	0.27459			
CF	.00001	—	—	—	—	—	—	—			
C_2F_2	.00001	.00001	—	—	—	—	—	—			
CH_4	.00010	.00009	.00007	.00005	.00005	.00006	.00015	.00066			
CO	.15670	.15700	.15770	.15828	.15850	.15853	.15831	.14854			
CO_2	—	—	—	—	—	—	.00006	.00369			
F	.00034	.00024	.00008	.00001	—	—	—	—			
H	.02322	.01952	.01079	.00341	.00058	.00003	—	—			
H_2	.24141	.24370	.24915	.25378	.25555	.25586	.25562	.25218			
HF	.31306	.31377	.31534	.31657	.31703	.31713	.31719	.31751			
H_2O	.00001	.00001	.00001	.00001	.00001	.00002	.00015	.00284			

[a]Mole fractions were computed for all 19 substances considered in this report but are omitted if less than 5×10^{-5}.

[b]Combustion temperature.

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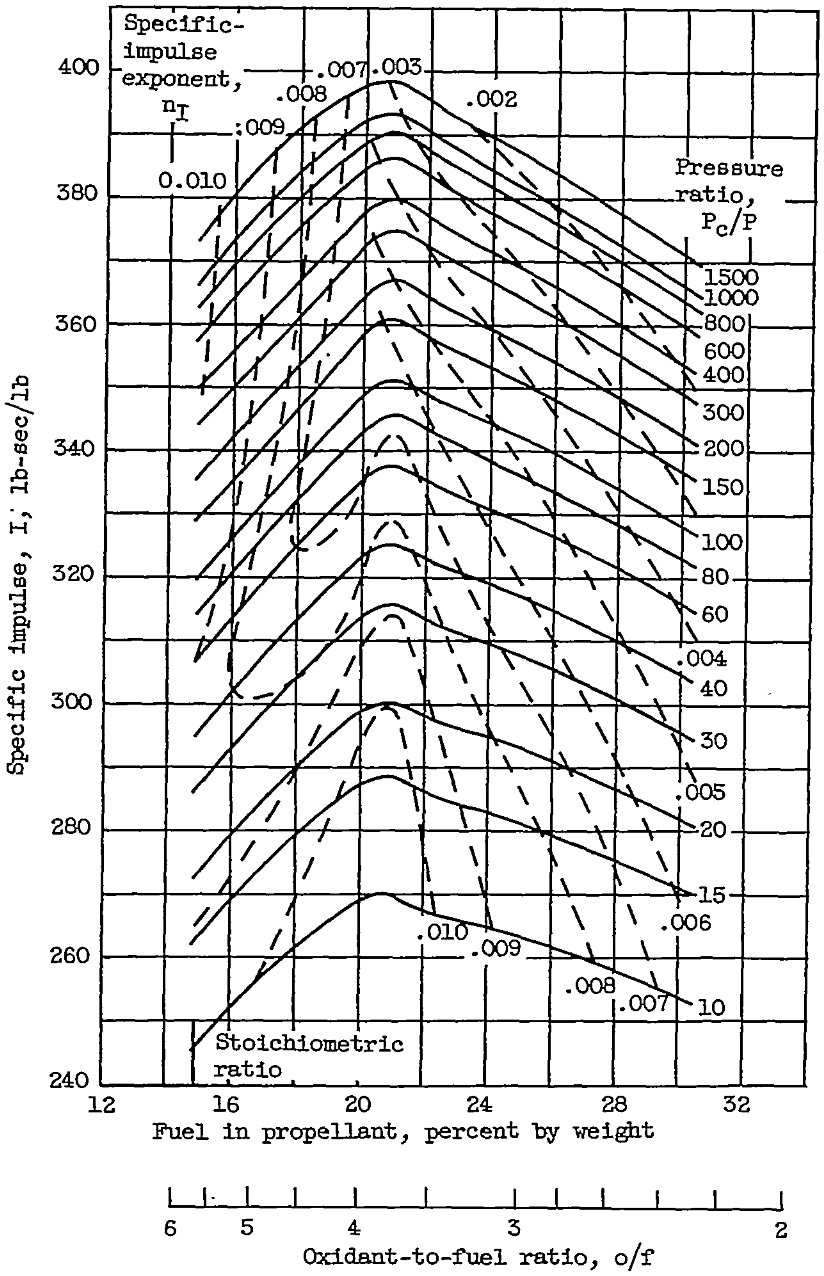

(a) Combustion-chamber pressure, 600 pounds per square inch absolute. Exponent n_I for use in equation $I = I_{600}\left(\frac{P_c}{600}\right)^{n_I}$.

Figure 1. - Theoretical specific impulse of JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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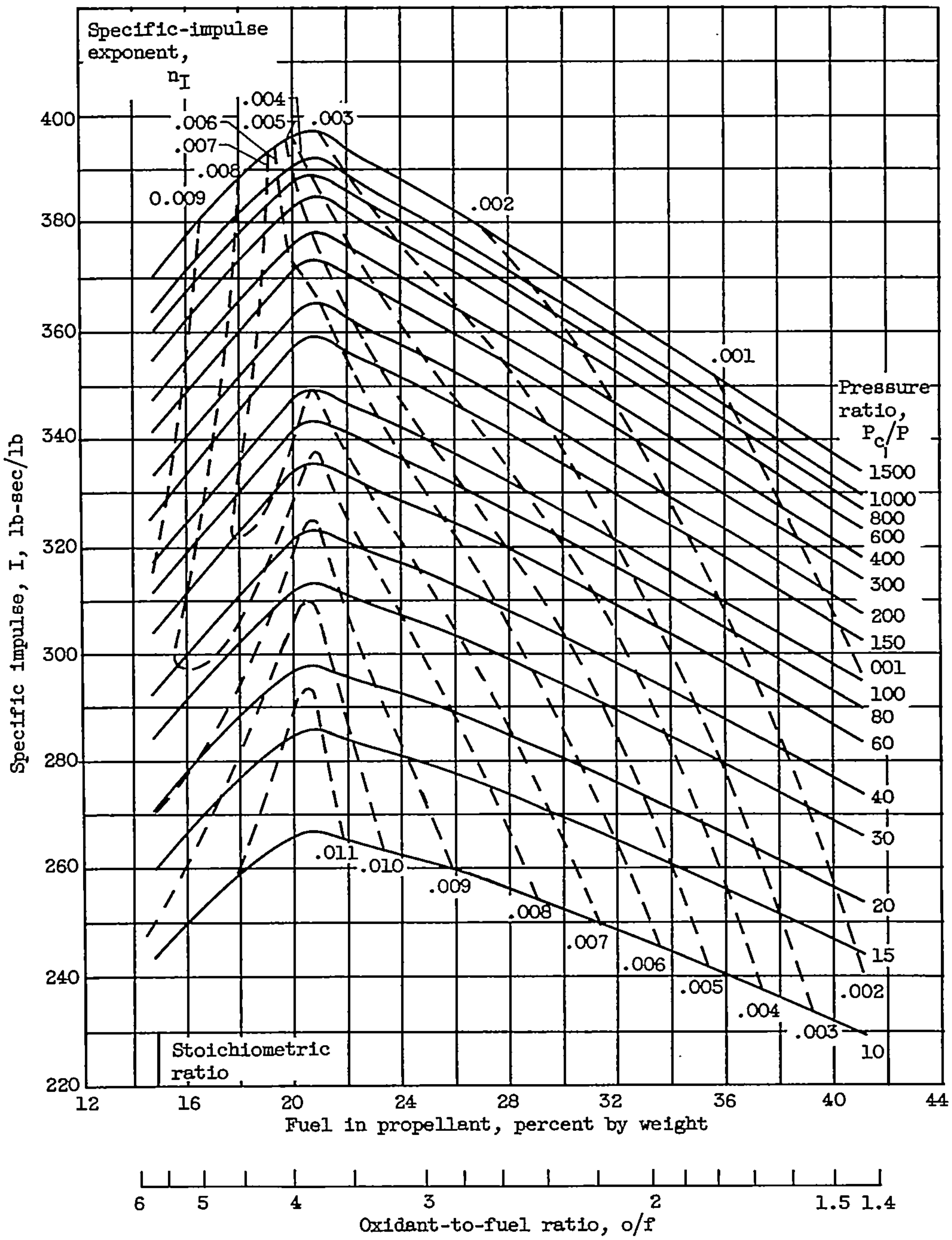

(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Exponent n_I for use in equation $I = I_{300}\left(\frac{P_c}{300}\right)^{n_I}$.

Figure 1. - Concluded. Theoretical specific impulse of JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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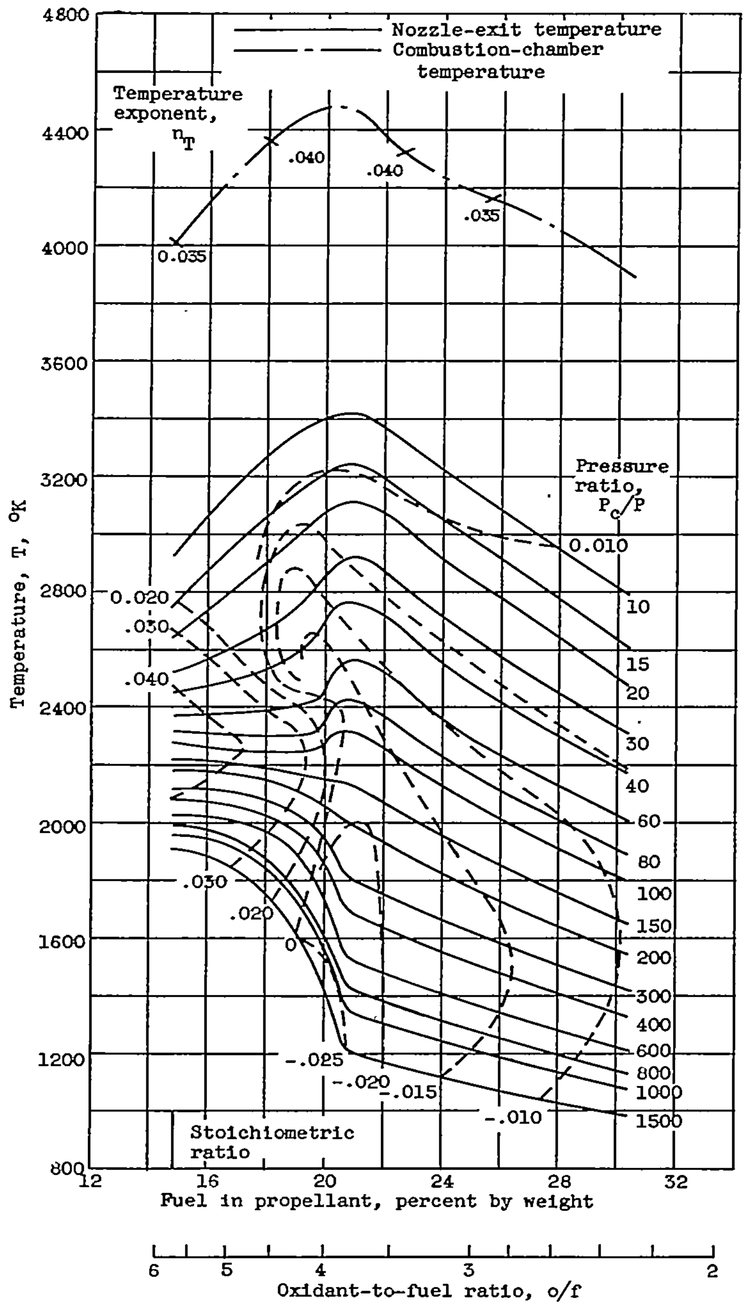

(a) Combustion-chamber pressure, 600 pounds per square inch absolute. Exponent n_T for use in equation

$$T = T_{600}\left(\frac{P_c}{600}\right)^{n_T}.$$

Figure 2. - Theoretical combustion-chamber and nozzle-exit temperatures for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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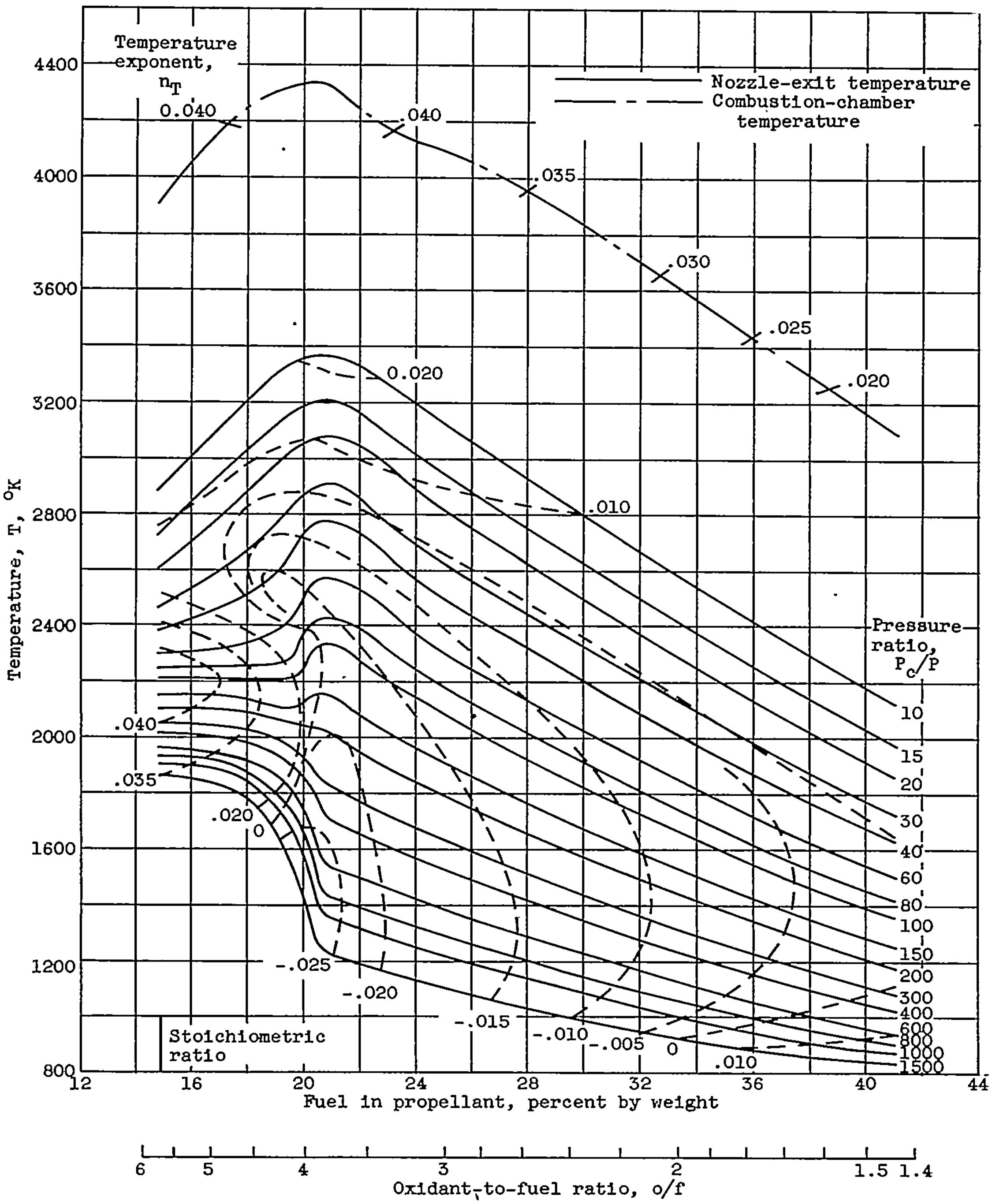

(b) Combustion-chamber pressure, 300 pounds per square inch absolute. Exponent n_T for use in equation $T = T_{300}\left(\frac{P_c}{300}\right)^{n_T}$.

Figure 2. - Concluded. Theoretical combustion-chamber and nozzle-exit temperatures for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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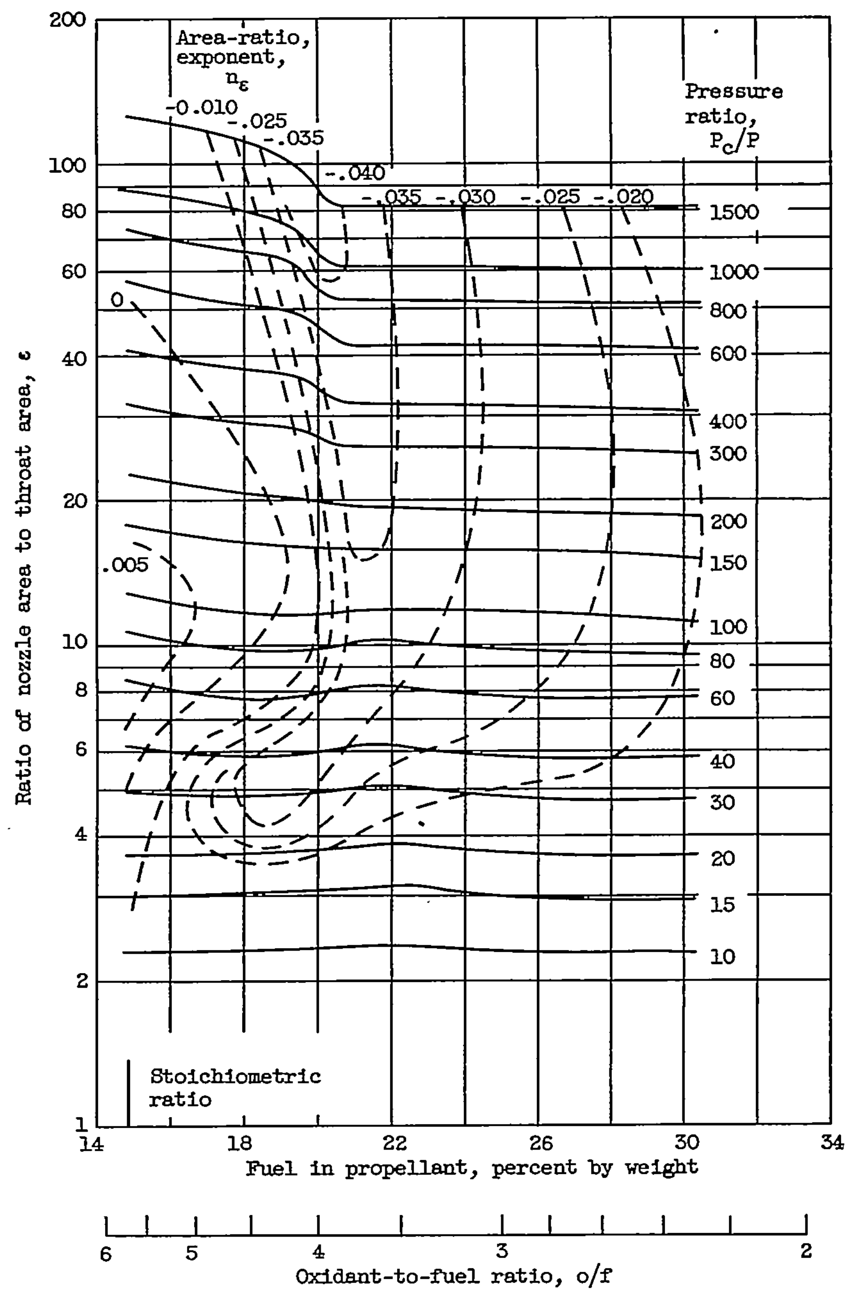

(a) Combustion-chamber pressure, 600 pounds per square inch absolute. Exponent n_ε for use in equation

$$\varepsilon = \varepsilon_{600}\left(\frac{P_c}{600}\right)^{n_\varepsilon}.$$

Figure 3. - Theoretical ratio of nozzle area to throat area for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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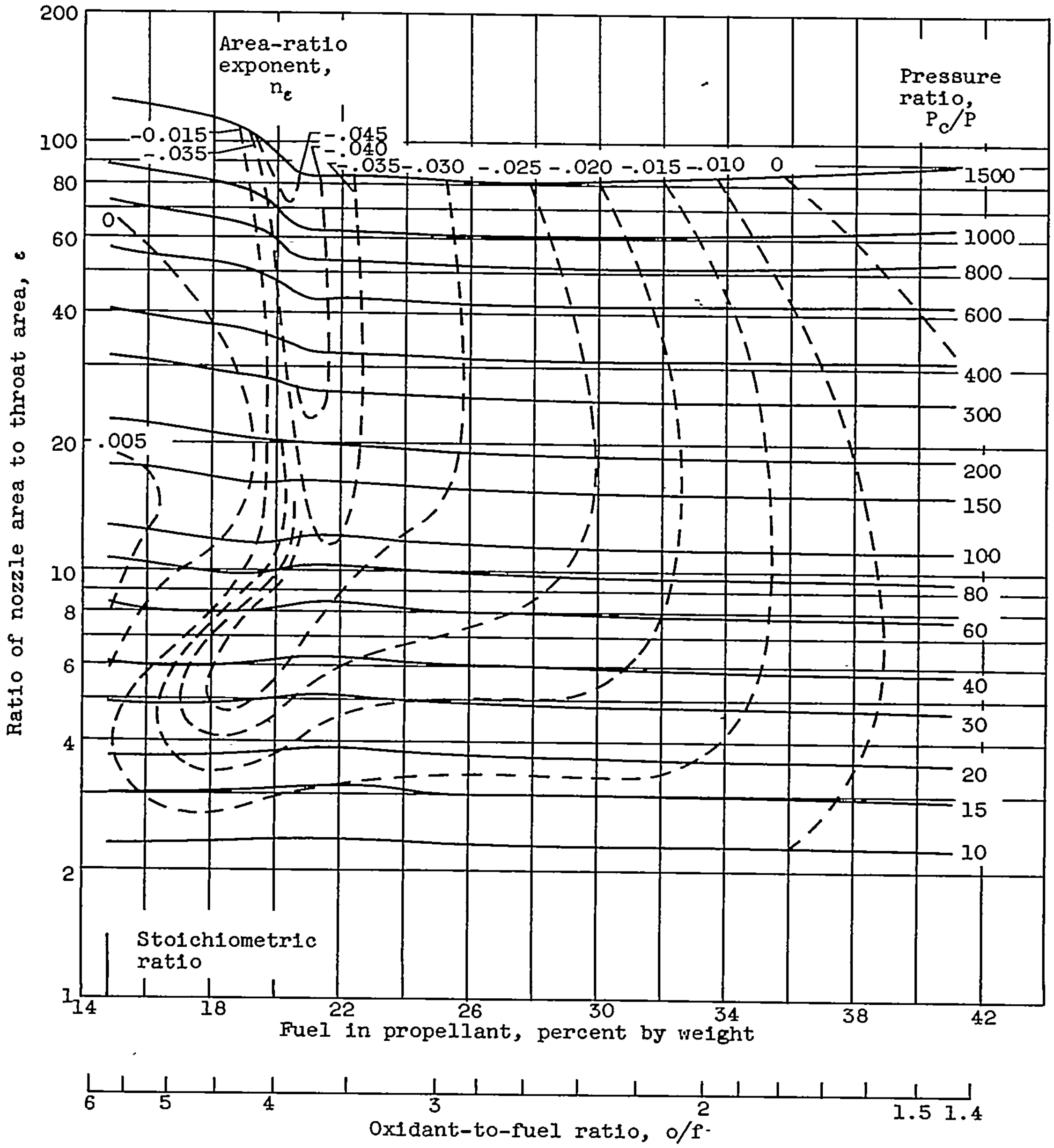
CM-6



(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Exponent n_ε for use in equation $\varepsilon = \varepsilon_{300}\left(\frac{P_c}{300}\right)^{n_\varepsilon}$.

Figure 3. - Concluded. Theoretical ratio of nozzle area to throat area for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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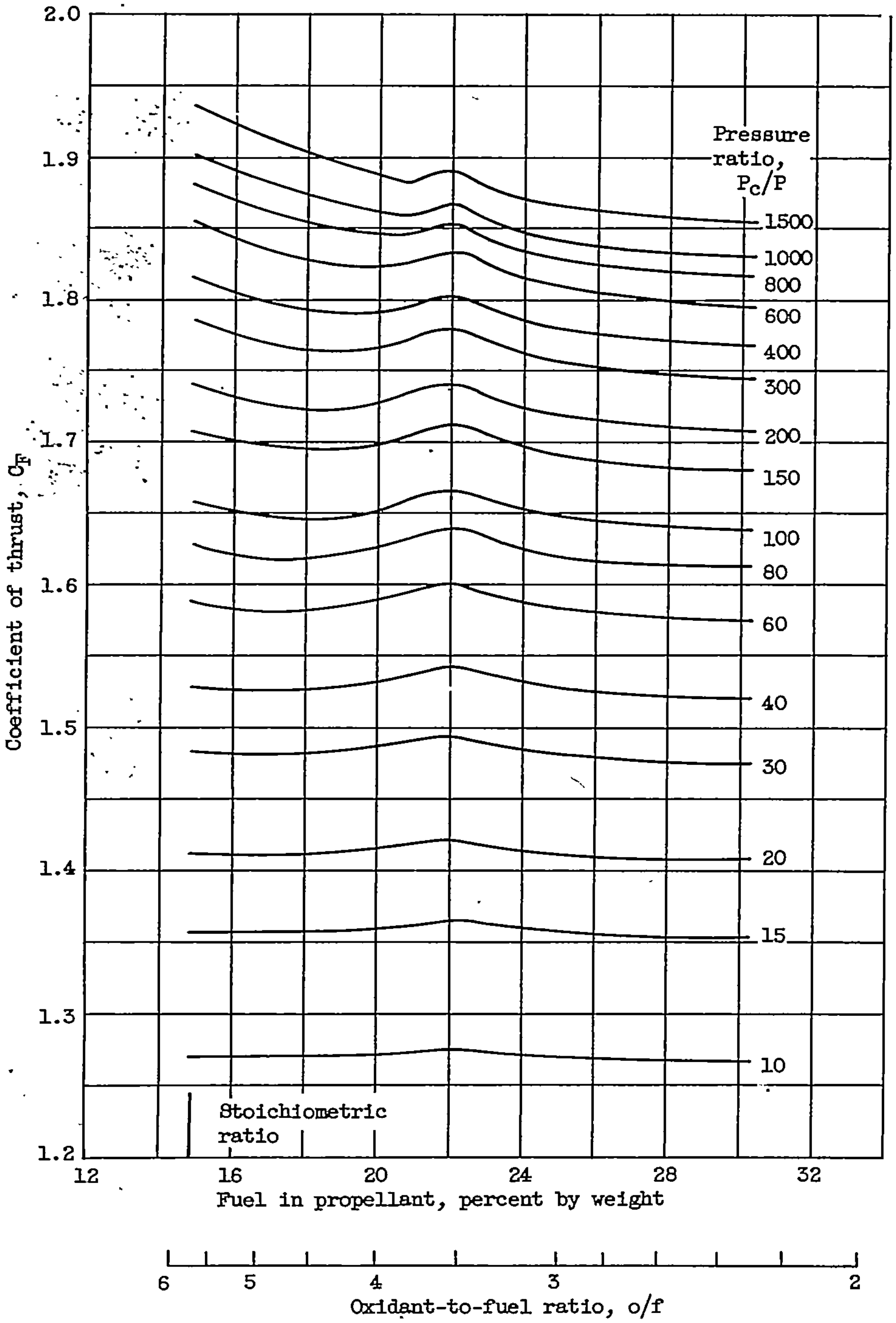

(a) Combustion-chamber pressure, 600 pounds per square inch absolute.

Figure 4. - Theoretical coefficient of thrust for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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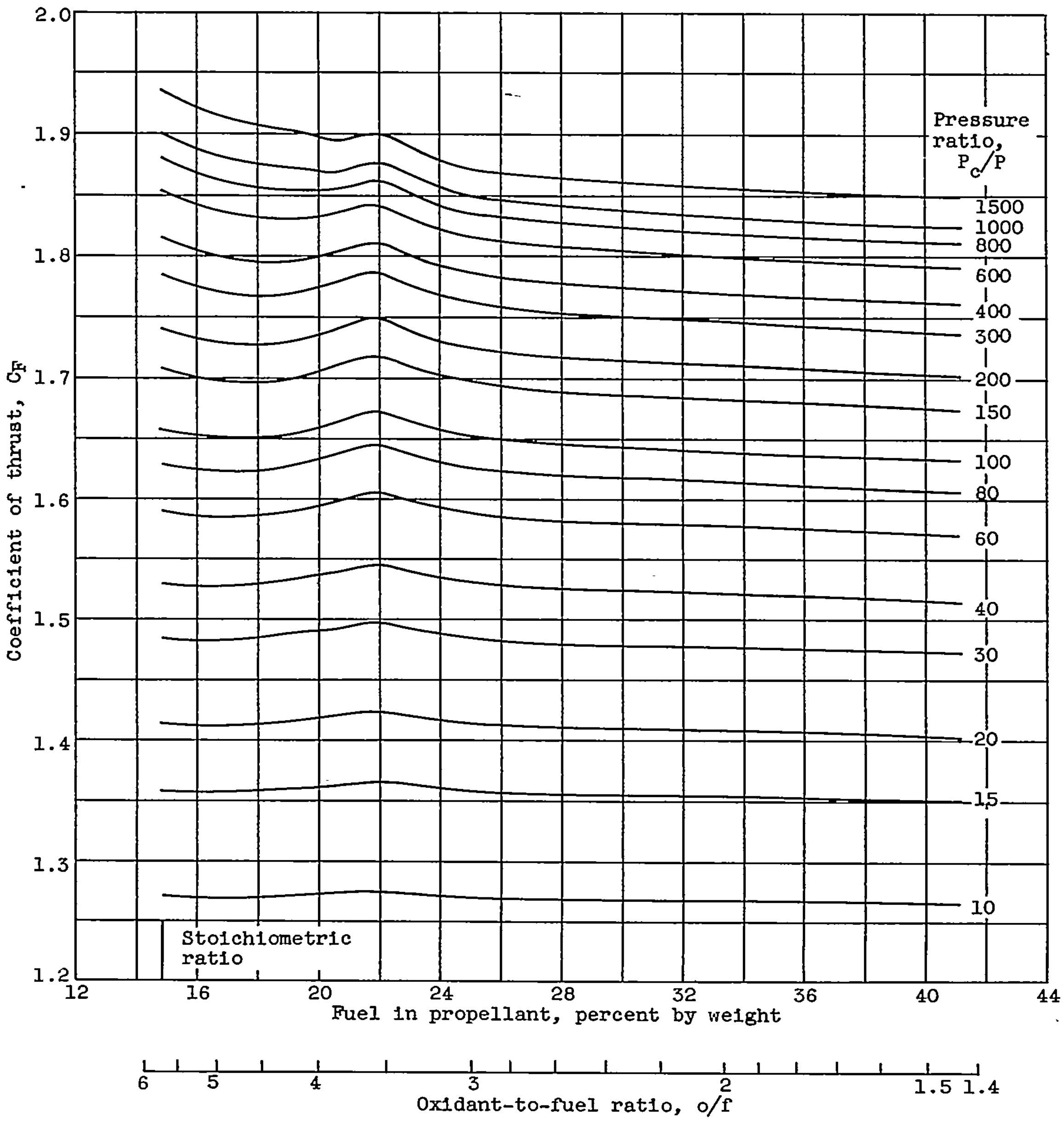
CM-6 back



(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Figure 4. - Concluded. Theoretical coefficient of thrust for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

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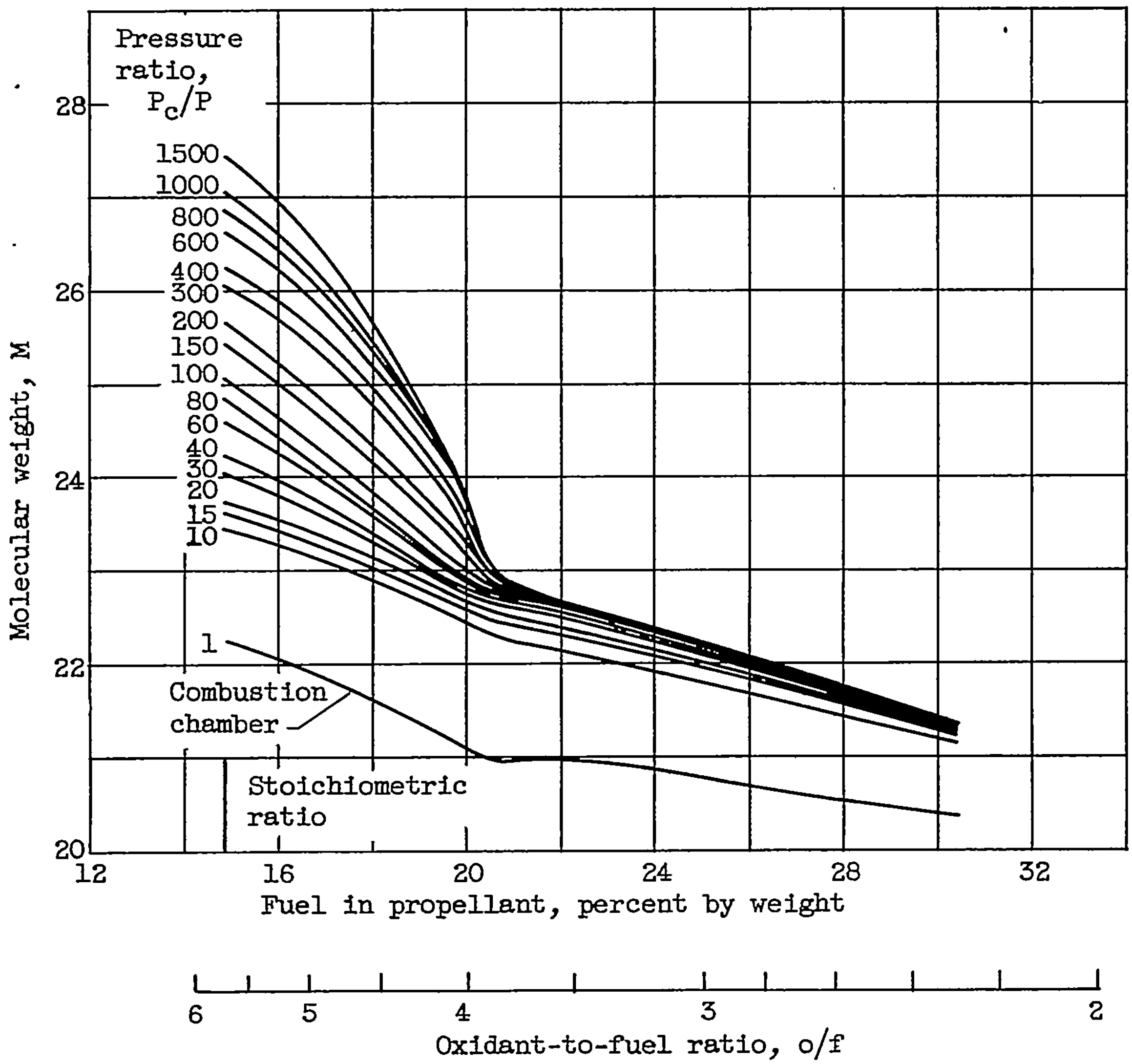
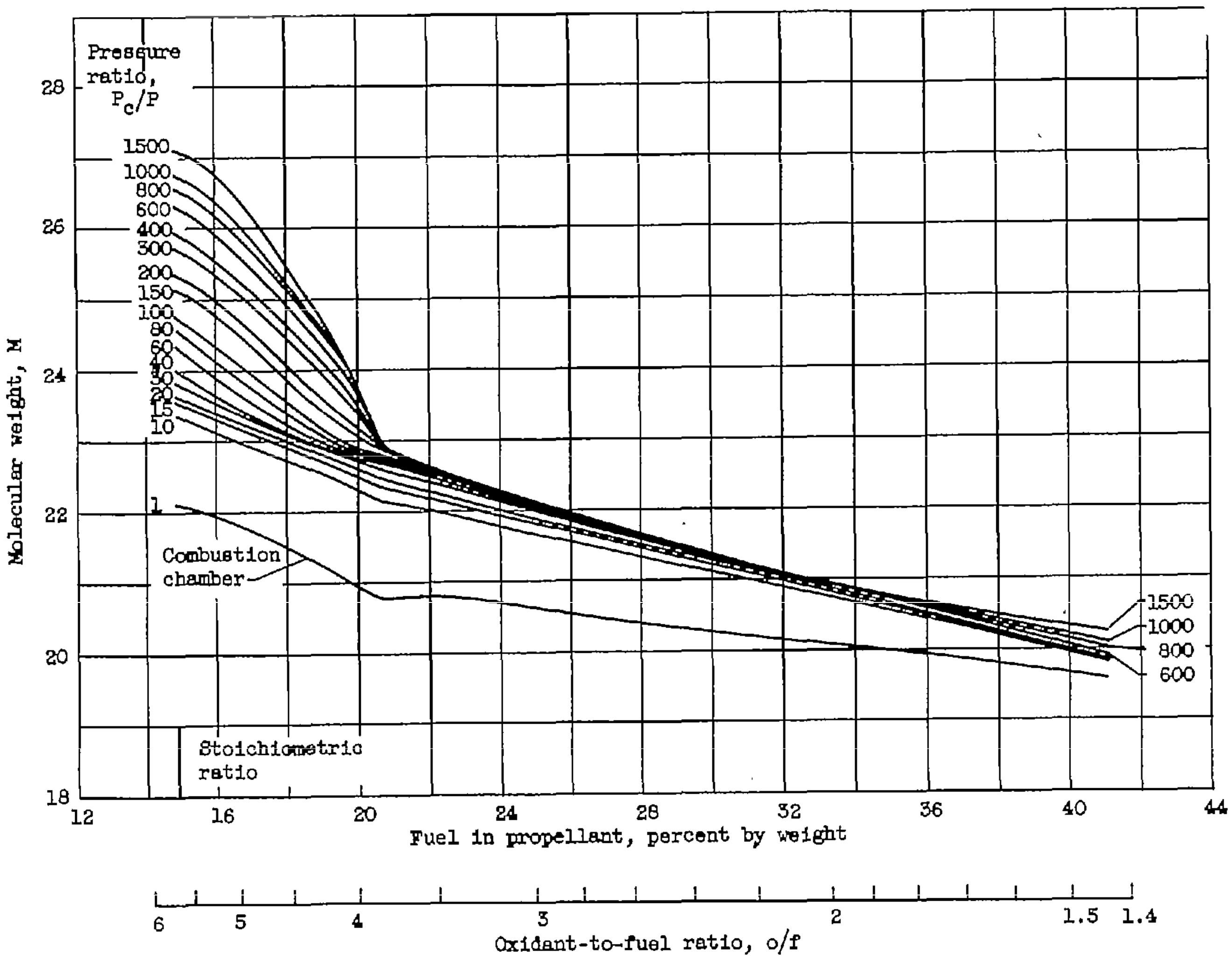


(a) Combustion-chamber pressure, 600 pounds per square inch absolute.

Figure 5. - Theoretical molecular weight for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

[redacted]



(b) Combustion-chamber pressure, 300 pounds per square inch absolute.

Figure 5. - Concluded. Theoretical molecular weight for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Equilibrium composition during isentropic expansion to pressure ratio indicated.

[redacted]

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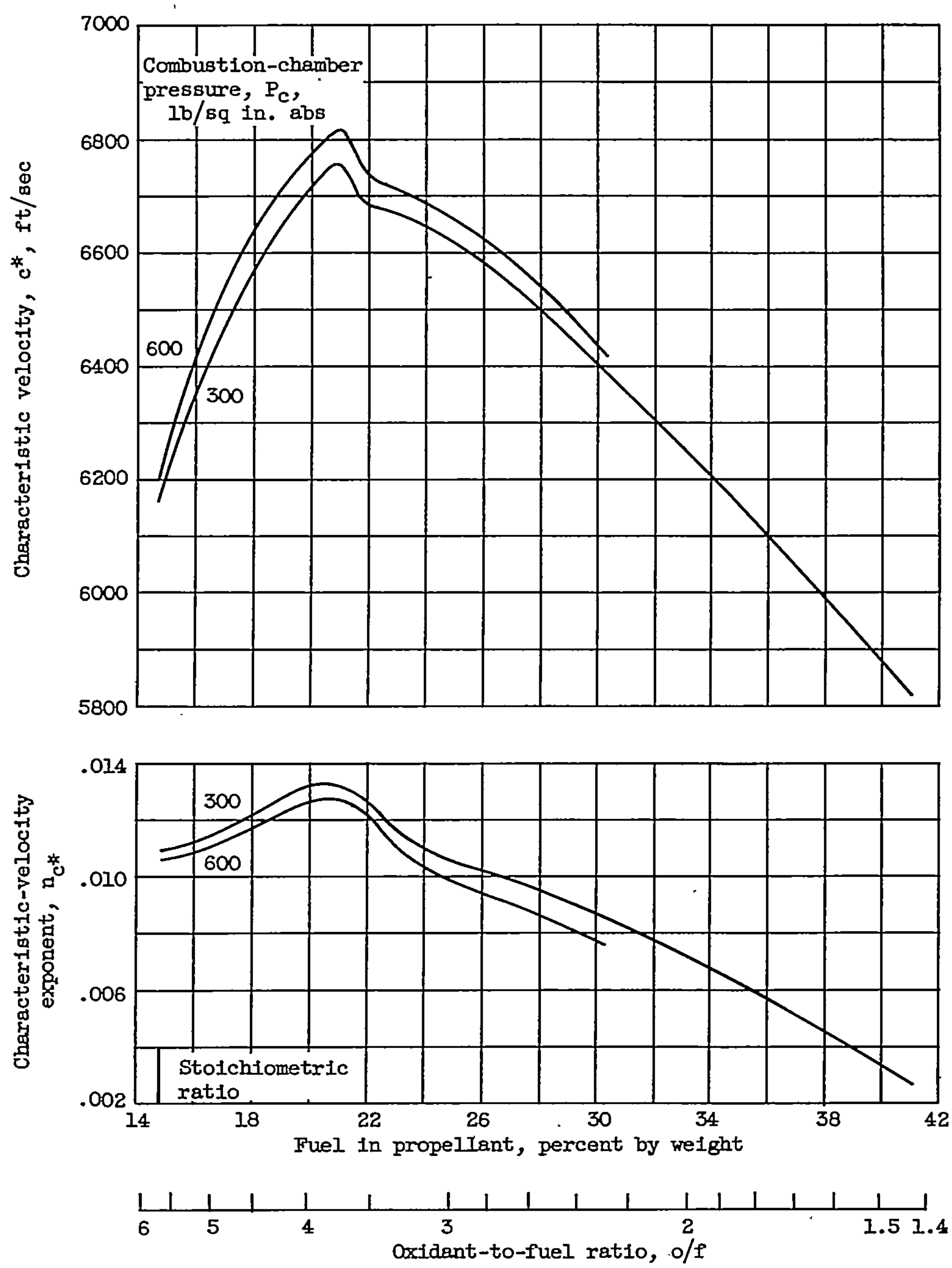

Figure 6. - Theoretical characteristic velocity and characteristic-velocity exponent n_{c^*} for use in equation $c^* = c_1^*\left(\frac{P_c}{P_{c,1}}\right)^{n_{c_1^*}}$. JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight; equilibrium composition during isentropic expansion from chamber pressure indicated.

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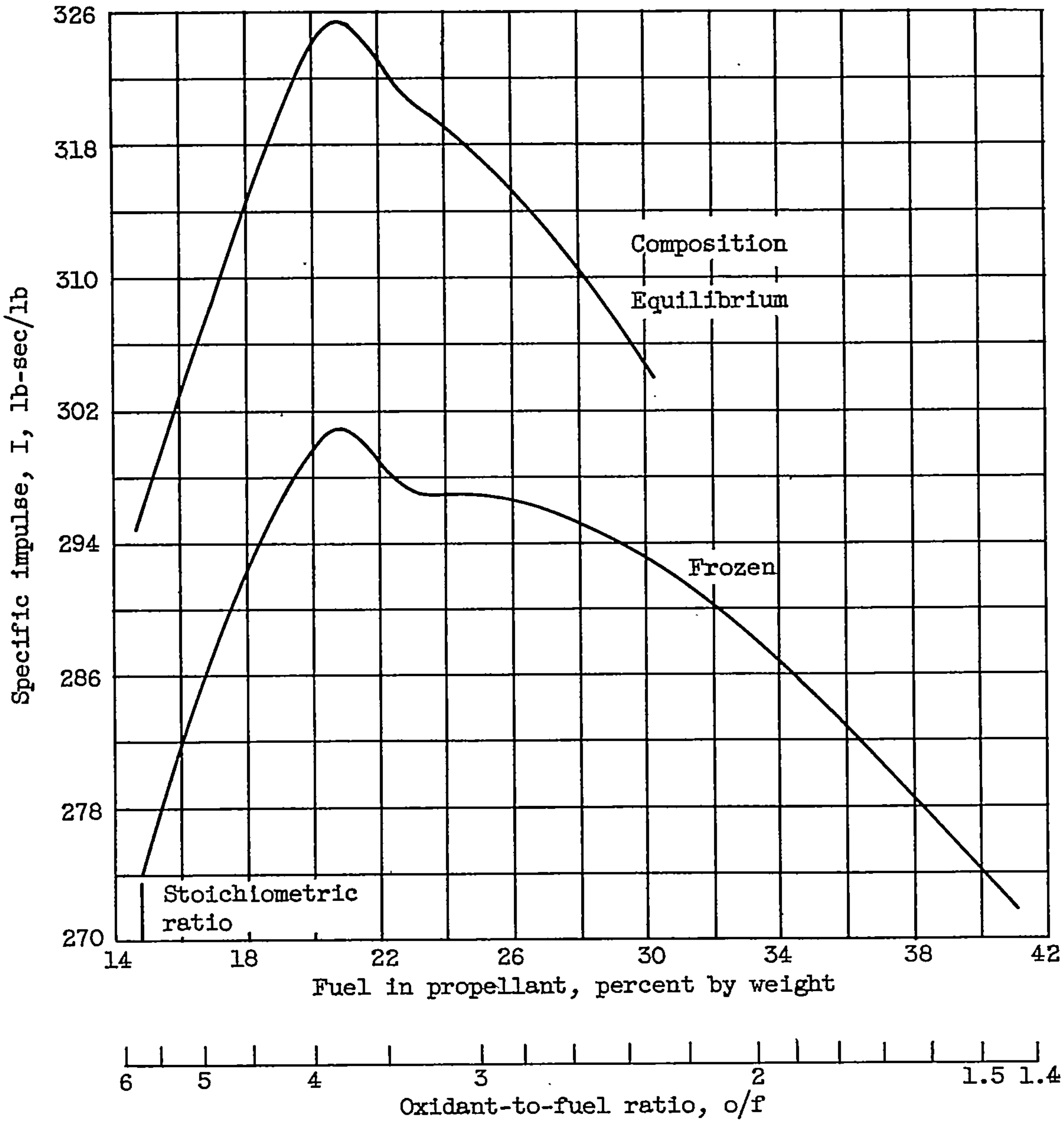

Figure 7. - Comparison of theoretical specific impulse assuming frozen and equilibrium compositions for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight. Combustion-chamber pressure, 600 pounds per square inch absolute; isentropic expansion to 1 atmosphere.

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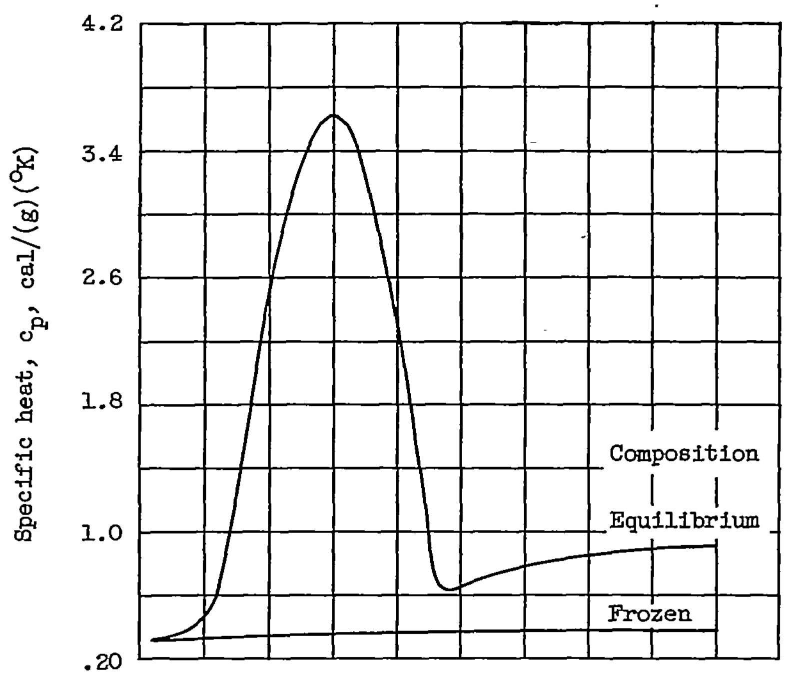
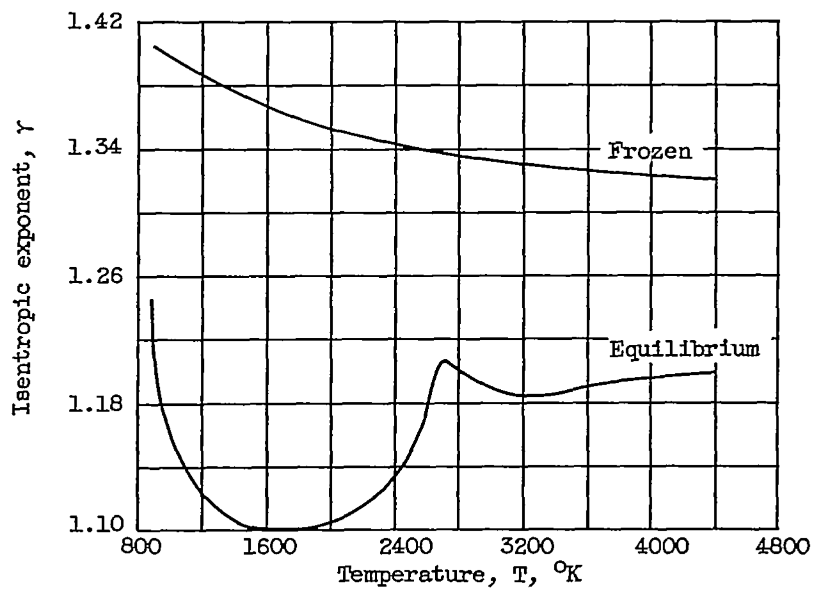


(a) Theoretical specific heat.



(b) Theoretical isentropic exponent.

Figure 8. - Variation of theoretical specific heat and isentropic exponent with temperature for both frozen and equilibrium compositions. Isentropic expansion; combustion-chamber pressure, 600 pounds per square inch absolute; stoichiometric equivalence ratio for JP-4 fuel with oxidant containing 70.37 percent liquid fluorine and 29.63 percent liquid oxygen by weight.

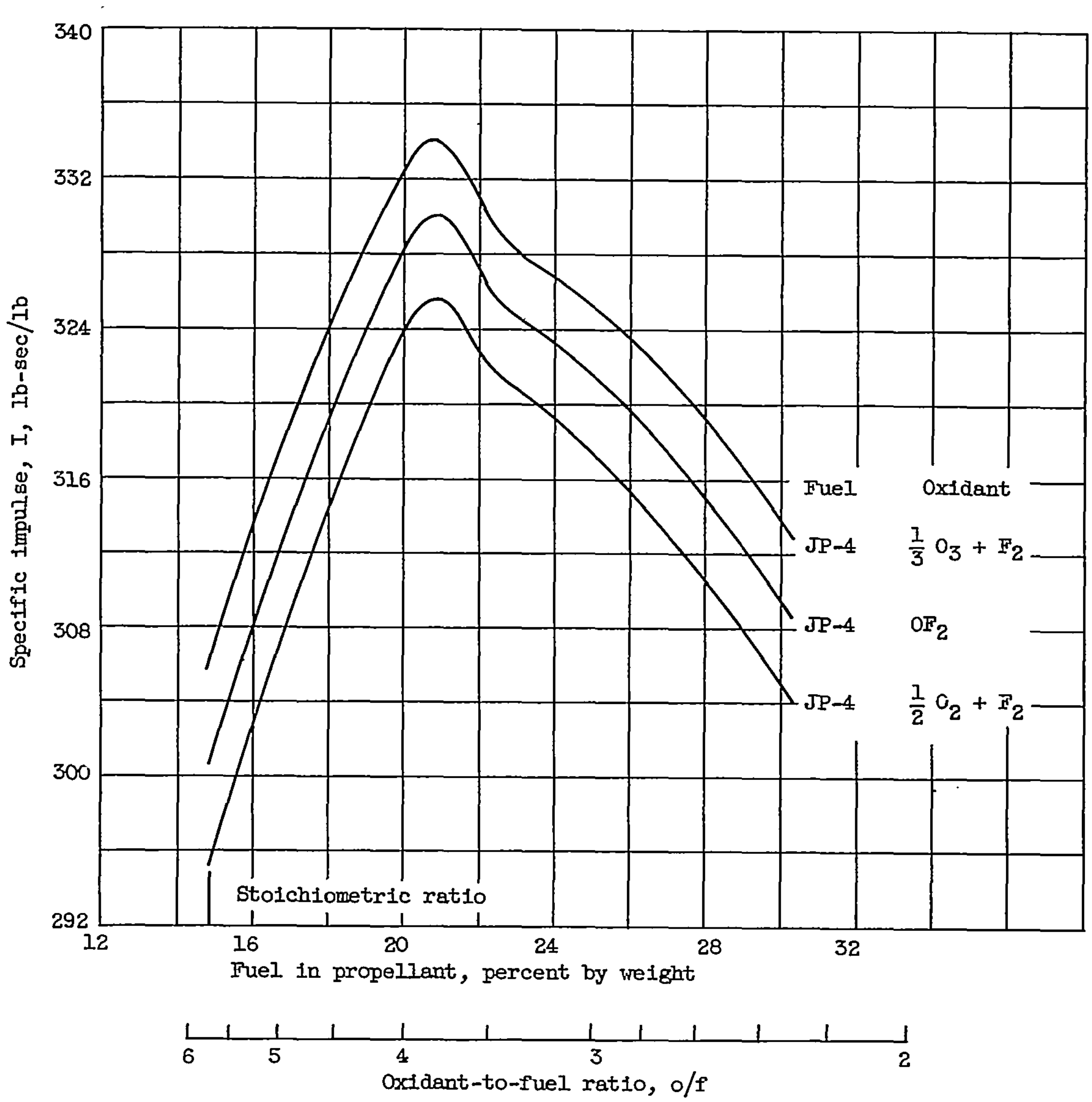


Figure 9. - Comparison of theoretical specific impulse for several propellants having same atom ratios but different heat contents. Combustion-chamber pressure, 600 pounds per square inch absolute; equilibrium composition during isentropic expansion to 1 atmosphere. Data for ozone-fluorine mixture and oxygen bifluoride as oxidants estimated by means of equation (25).